FCF-DOC-003C

Baseline System Description (BSD)

ISS Fluids and Combustion Facility (FCF)

PRELIMINARY DESIGN
Revision C
October 2000

AUTHORIZED by CM when under FORMAL Configuration Control	
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Preface

The National Aeronautics and Space Administration (NASA) is developing a modular, multi-user experimentation facility for conducting fluid physics and combustion science experiments in the microgravity environment of the International Space Station (ISS). This facility, called the Fluids and Combustion Facility (FCF), consists of three test platforms: the Fluids Integrated Rack (FIR), the Combustion Integrated Rack (CIR), and the Shared Accommodations Rack (SAR). This FCF Baseline System Description document presents the state of design of the Fluids and Combustion Facility as of October 27, 2000. This release of this document has been prepared to support the Fluids and Combustion Facility Preliminary Design Review scheduled for the fourth quarter of 2000.

October 2000	ISS Fluids and Combustion Facility (FCF) Baseline System Description (BSD)	FIR-DOC-003

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REVISION PAGE

FCF-DOC-003C
FLUIDS AND COMBUSTION FACILITY (FCF)
BASELINE SYSTEM DESCRIPTION

REVISION	DATE	DESCRIPTION OF CHANGES OR ECOs INCORPORATED	VERIFICATION and DATE
—	06/98	Initial Draft Prepared for Hardware Concept Review	June 1998
A (draft)	11/12/98	Draft of first Upgrade following HCR	11/12/98
A	12/15/98	Release of Revision A	12/15/98
B	03/17/99	Release of Revision B for the CIR PDR	03/17/99
C	10/27/00	Release of Rev. C for the FCF PDR	10/27/00

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Chapter 1 - FCF Overview

1 FCF OVERVIEW

1.1 BSD Introduction

This section describes the purpose, scope, and format of this *Baseline System Description* (BSD) document. It also explains the relationship between this and other key Fluids and Combustion Facility (FCF) project documents.

1.1.1 BSD Purpose

The *Baseline System Description* document provides a description of the International Space Station (ISS) Fluids and Combustion Facility (FCF) in an easily understood format of illustration and narrative. This document is used as a communication tool, and also use it for briefings, studies, and cost estimates.

The FCF system described in the BSD is a response to the requirements stated in the *FCF Science Requirements Envelope Document* (SRED), to the *ISS Interface Requirements Document*, and to other requirements and constraints.

The BSD is a living document. As the FCF facility concept evolves, the BSD will be updated to reflect the latest design and planning.

1.1.2 BSD Scope

The BSD covers the entire FCF system for its entire life cycle. All the flight and ground hardware, software, and operations are included. The life cycle extends to the ultimate decommissioning and disposal of the FCF.

The following figure illustrated the organization and outline of this version of the FCF BSD

FCF BSD Overview

Section 1 - **FCF Overview**: Presents an overview of the FCF program with mission, scope and schedule.

Section 2 - **Reference Documents**: Provides a listing of the documents containing FCF requirements and design.

Section 3 - **ISS Resources**: Delineates the services provided by the ISS

Section 4 - **FCF System Design**: Statuses the current design of the FCF at the highest level.

Section 5 - **Common Hardware Design**: Presents the design of the hardware common to all three FCF racks.

Section 6 – **FCF Software Design:** Statuses software development at the facility level.

Section 7 - **Supporting Engineering**: Explains support functions and processes involved.

Section 8 – **Utilization and Integration**: Describes interfaces to both ISS and the PI's.

Section 9 – **FCF Operations**: Describes both operations on-orbit and on the ground.

Section 10 - **Acronyms**

Appendix A - **CIR BSD**: Describes CIR-unique hardware and operations
Appendix B - **FIR BSD**: Describes FIR-unique hardware and operations
Appendix C - **SAR BSD**: Describes SAR-unique hardware and operations

1.2 FCF Introduction

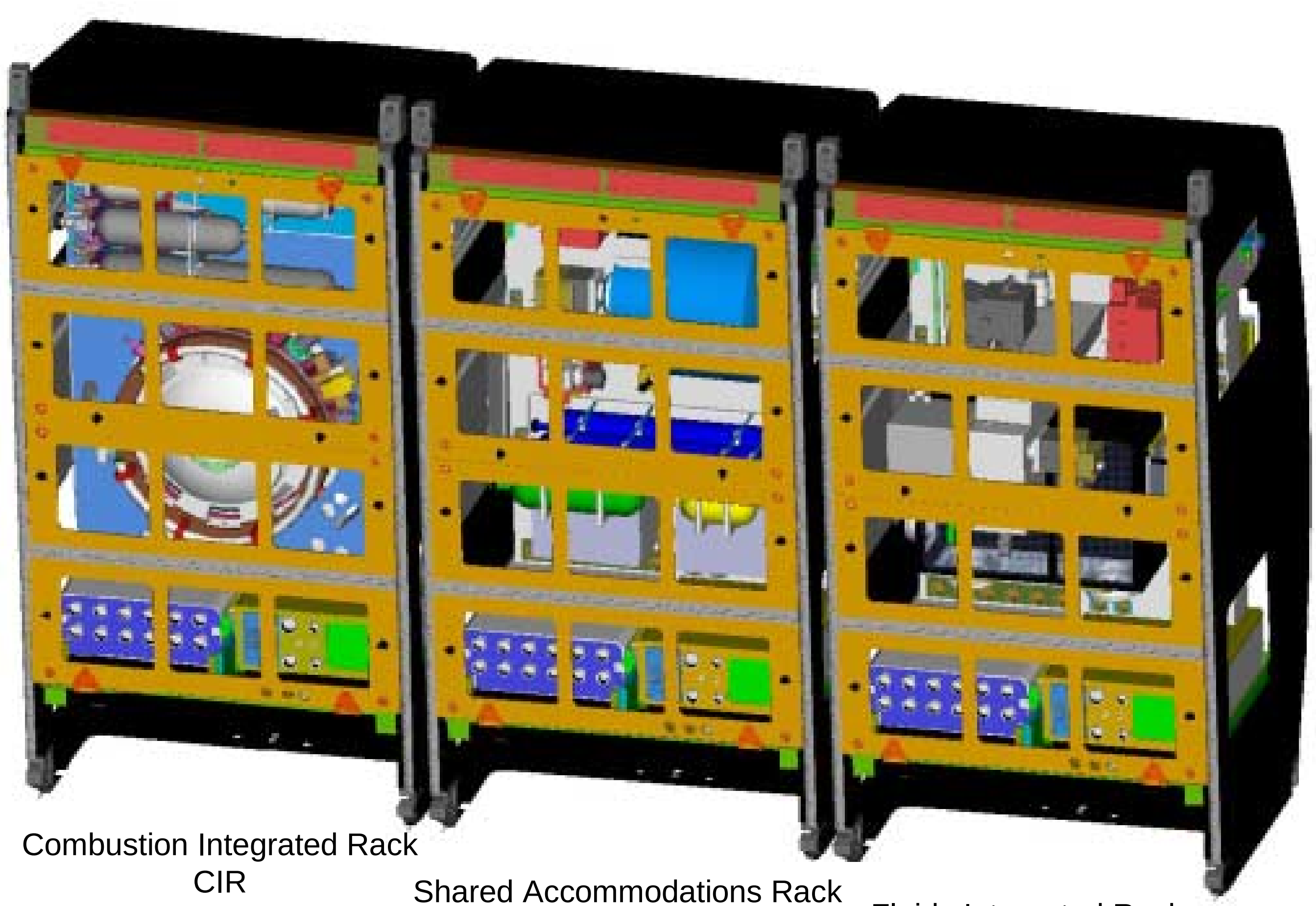
The Fluids and Combustion Facility (FCF) is a modular, multi-user facility designed to accommodate fluids and combustion experiments on-board the U.S. Laboratory Module of the International Space Station (ISS). The extended duration microgravity environment of the ISS will enable microgravity research to enter into a new era of increased scientific and technological data return. The FCF is being designed to increase the amount and quality of scientific and technological data, while decreasing the development cost of individual experiments relative to other avenues of performing such experiments.

The FCF will occupy three International Standard Payload Racks (ISPRs) to support sustained, systematic microgravity fluid physics and combustion science research on board the ISS. The ISPRs comprising the FCF have been designated as the Combustion Integrated Rack (CIR), the Fluids Integrated Rack (FIR) and the Shared Accommodations Rack (SAR).

The initial deployment of the FCF will be the CIR, which will function independently as a single integrated rack allowing for early science research opportunities while accommodating ISS launch manifests and resource availability. The CIR is currently scheduled to be launched on Utilization Flight #3 (UF-3). The second ISPR of the FCF to be deployed will be the FIR, which will also function independently as a single integrated rack. The FIR launch is currently scheduled for UF-5. The CIR and the FIR will operate independently until the launch of the SAR on UF-7. While operating independently, neither the CIR nor the FIR will meet the full performance requirements of the FCF Science Requirements Envelope Document (SRED). Consequently, Once the FCF is complete (after UF-7), upgrades will be performed to offer enhanced capabilities to meet the full set of facility science requirements.

The following page illustrates the International Space Station, Fluids and Combustion Facility.

International Space Station (ISS) Fluids and Combustion Facility (FCF)



Combustion Integrated Rack
CIR

Shared Accommodations Rack
SAR

Fluids Integrated Rack
FIR

1.3 FCF Mission and Scope

The Space Station *Fluids and Combustion Facility* (FCF) primary mission is the following:

- To support accomplishment of NASA Microgravity Science and Applications Division (MSAD) Program objectives requiring sustained, systematic microgravity fluid physics and microgravity combustion science research on board the International Space Station (ISS).

To accomplish the mission FCF shall:

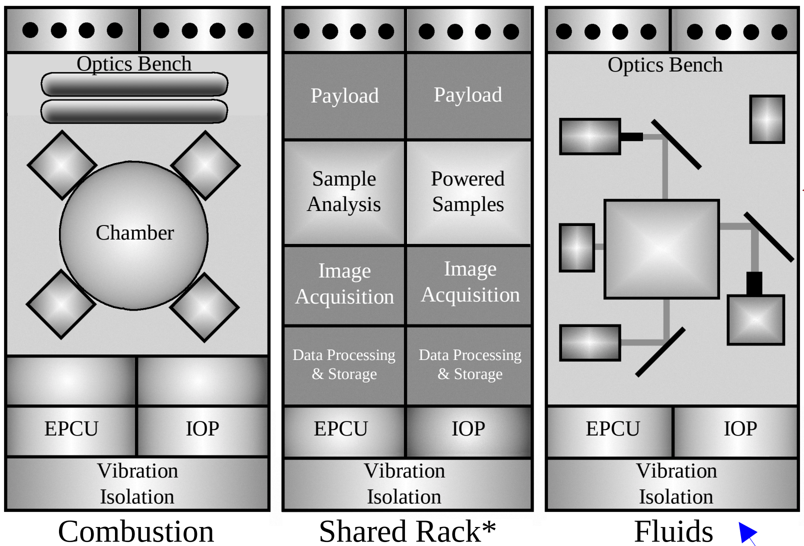
- Be a permanent multidiscipline research facility occupying three payload racks on-board the United States Laboratory Module (US Lab) of the International Space Station (ISS).
- Include in its scope both the on-orbit and ground based hardware, training, operations, and virtually all other activities needed to accomplish the mission.

To support multiple disciplines FCF shall:

- Provide the common on-orbit infrastructure needed by the fluids and combustion disciplines, and it shall provide on-orbit accommodations for the experiment specific hardware needed by individual fluids and combustion scientists.
- Provide generic on-orbit accommodations that may be used by any discipline.

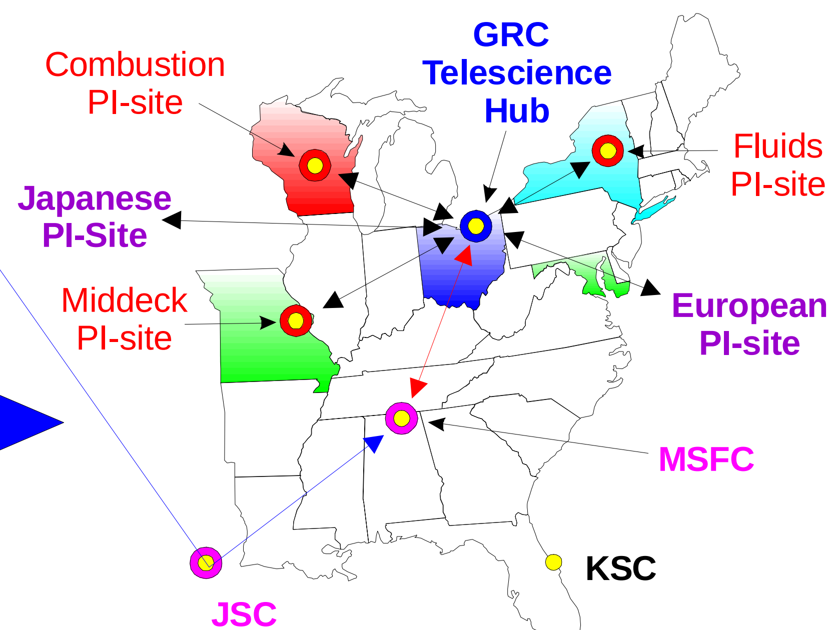
The following figure illustrates the Mission and Scope of FCF.
FCF primarily supports sustained fluid physics and combustion science research on the ISS. FCF provides flight hardware, ground systems, training, and all other needed equipment and operations.

FCF Mission and Scope



Space Station Based Equipment

- o Fluid Physics Rack
- o Combustion Science Rack
- o Shared Rack
  - > Fluids, combustion, and other payloads



Earth Based Operations

- o Experiment development
- o Astronaut training
- o Telescience at PI-site and GRC TSC

*Shared Accommodations Rack is used for fluids and combustion hardware that is either shared or does not fit in the fluids or combustion racks (e.g., image acquisition, storage, and processing). May also accommodate hardware from other disciplines. Layout shown is for example purposes as the locations of equipment is not finalized.

1.3.1 Principal Investigator (PI) Hardware

Principal Investigator (PI) hardware is the *key* to FCF adaptability. These experiment specific components are individually engineered for each new PI's experiment. They customize FCF to perform the experiment the most effective way.

To meet the FCF requirement of at least 10 typical PI experiments per year, FCF had to be designed to keep *typical* PI hardware light (typically 25 to 75 kilograms) and inexpensive (cheaper than a typical middeck package) while maintaining the capabilities of major Spacelab hardware. This is feasible because FCF keeps generally useful hardware semi-permanently on-orbit (e.g. cameras, computers, actuators, combustion chamber, optical fixtures, light sources) and offers permanent shared use ground facilities.

PIs will only provide items truly unique to their experiment. FCF calculations indicate that these items will usually fall within the desired weight, volume, and cost limits.

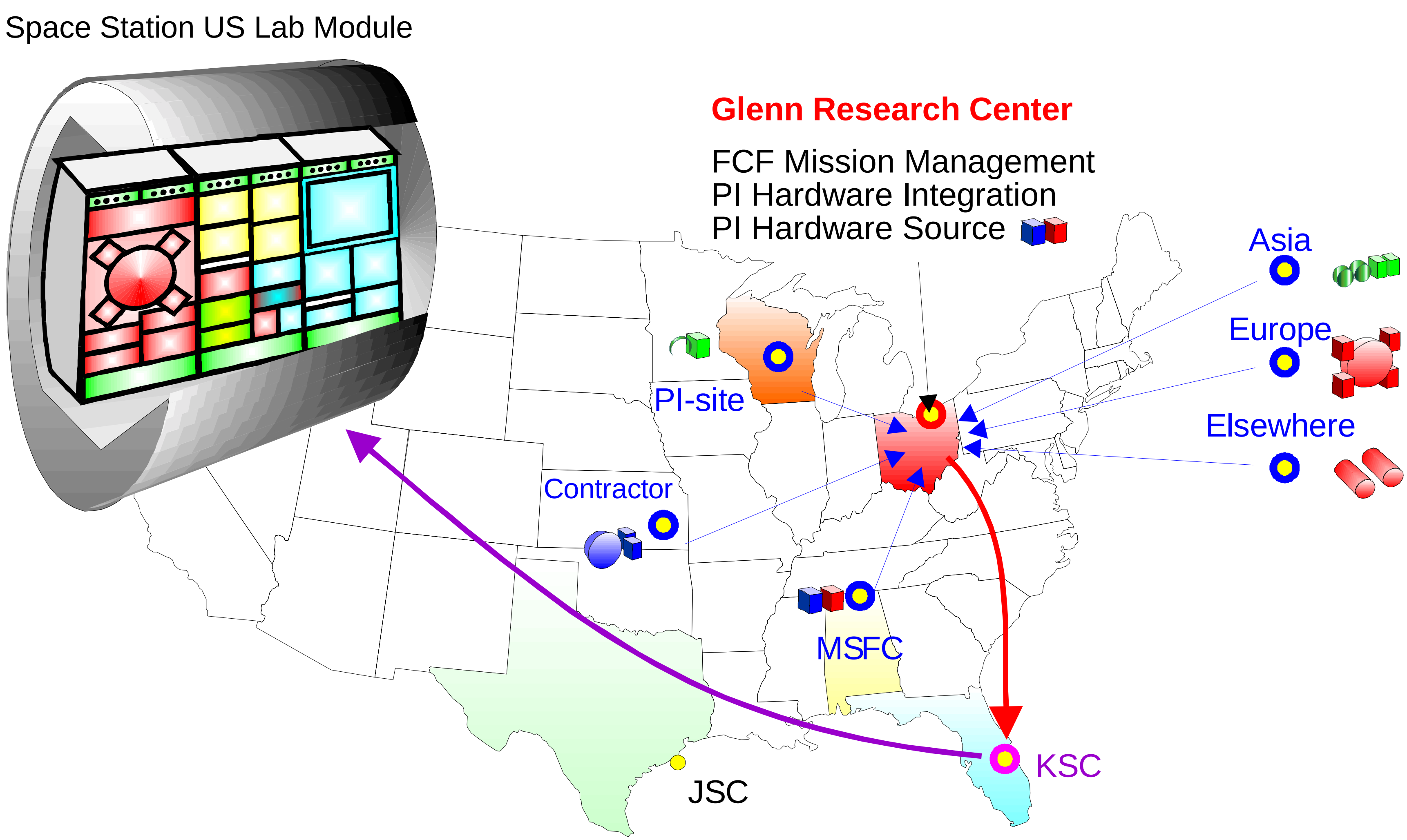
PI hardware can be developed by any organization. FCF will make design guide documents and expert advice available to all PI hardware developers.

PI hardware can utilize middeck packaging, or flexible FCF configurations. Moreover, they can tap into FCF's facility class imaging and commanding capabilities.

The requirements for the PI's experiment and specific hardware will be contained in the *Science Requirements Document* (SRD) for that experiment. Given mature requirements, it should be possible to build the PI hardware in one to two years versus the four to five years currently required to build self contained apparatuses of similar capability.

The following figure illustrates the potential sources for PI specific hardware used to customize FCF to perform a given experiment.
Such hardware is anticipated to come from all over the earth, and FCF is already dealing with potential partners in Asia and Europe. Interest is in both the fluids and combustion elements and the Middeck class accommodations.

PI-specific Hardware Source Concept



1.4 FCF System Definition

During the operations phase, the FCF system will be made up of the following key items.

Flight Segment

- Flight Unit (CIR, FIR, SAR) - 3 racks

Ground Segment

- Ground Integration Unit at GRC identical to flight - 3 racks
- Web Server, supplements TSC and provides flight like graphical interface

Development and Training Equipment

- FCF Engineering Unit Trainer at GRC (3 racks)
- PTC Trainer at JSC having functionality appropriate to that task - 3 racks

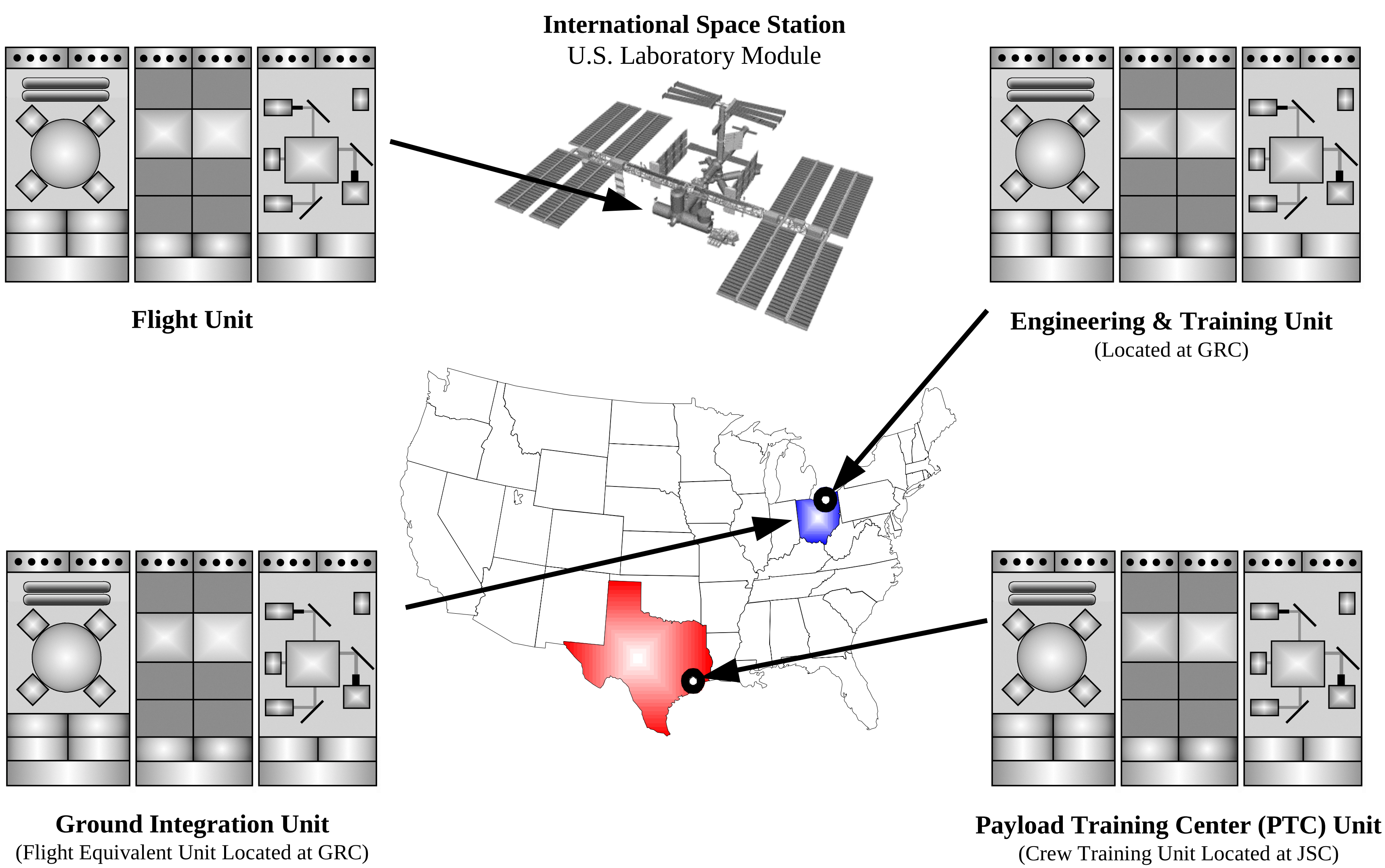
Support

- Engineering Model Interface Servicer
- Rack Handling Adapter & Shipping Container*
- Suitcase Test Environment for Payloads (STEP)*
- Payload Rack Checkout Unit (PRCU)*

* ISS Provided

The following figure illustrates the four flight like systems being built as part of the FCF project.
The Ground Integration Unit is functionally equivilent to the flight unit and is used to verify PI hardware and upgrades. The PTC trainer is required by the ISS Program.

FCF System Hardware



1.4.1 Flight Segment

The FCF *flight segment* consists of the three powered rack facility plus one rack (or equivalent volume) of unpowered stowage located on the ISS. The three powered racks are called the *Shared Accomodations Rack (SAR)*, *Fluids Integrated Rack (FIR)*, and *Combustion Integrated Rack (CIR)*.

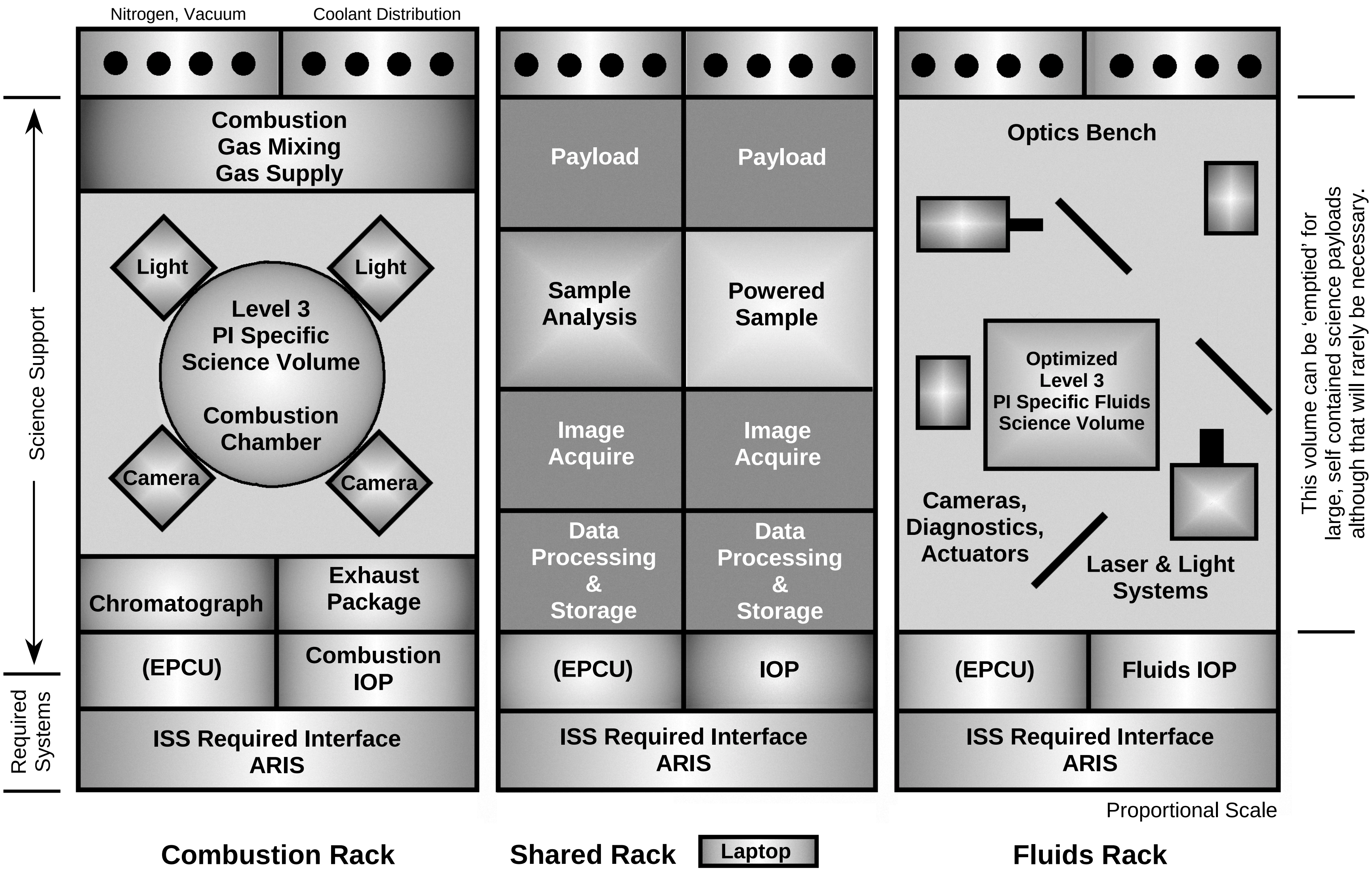
Functionality does cut across rack interfaces. For example, command and data management is designed as *one system* with components in all three racks.

The three on-orbit powered racks enable the following general functions:

- Shared functions: Includes functionality, hardware, and software needed by all the supported scientific disciplines (i.e. common hardware and software):
  - Structural hardware including all three ISPRs (racks), all standardized packages (drawers), and structural interfaces common to all three racks.
  - Power control and distribution equipment.
  - Environmental controls including cooling and fire detection & suppression.
  - Command, data management, image processing, and communication hardware and software.
  - Active Rack Isolation System (ARIS) hardware.
  - Stowage (spares and science hardware)
  - Middeck locker type accommodations
  - Includes scientific sensors such as cameras.
- Fluid Physics functions: Functions, hardware, and software for fluid physics experiments are located primarily in the Fluids Element located in the FIR.
- Combustion Science functions: Functions, hardware, and software for combustion science experiments are located primarily in the Combustion Element located in the CIR.
- Small Experiment Package functions: These functions typically reside inside the experiment package (e.g., middeck packages). However, small experiment packages can utilize FCF advanced functionality such as commanding and imaging.
- Microgravity Measurement functions: SAMS-II provides microgravity measurement for FCF.

The following figure depicts the on-orbit flight segment of FCF.
Common functions are distributed among the three powered racks. Fluid science and combustion science functions are located in their respective racks. Middeck payloads can use FCF capabilities such as imaging.

ISS FCF Flight Segment Block Diagram



1.4.2 Ground Segment

The Ground Segment works with the Flight Segment during a mission to accomplish the scientific objectives. The Ground Segment is comprised of the following elements:

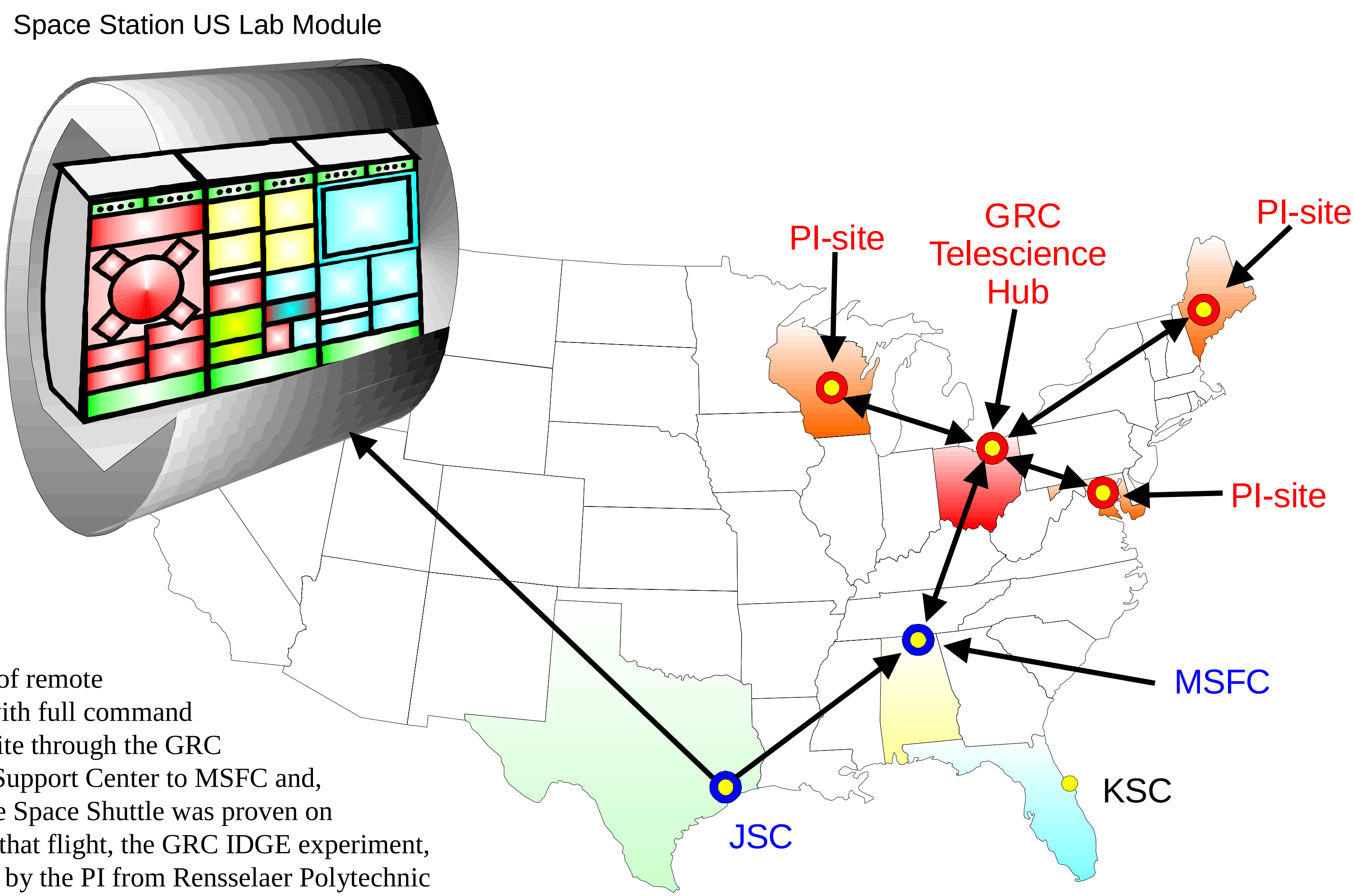
- FCF Embedded Web Technology (EWT) Server: The FCF software team will develop the EWT to interface with Enchanced HOSC System (EHS) and Telescience Resource Kit (TreK). A ground based embedded web server will provide an interface similar to the on board crew interface.
- Ground Integration Unit (GIU): The GIU located at NASA/GRC duplicates the Flight Segment. In addition to running end to end tests with PI specific hardware prior to their launch, it will be used for troubleshooting Flight Segment problems and simulating on orbit operations. It will be capable of being controlled remotely from the TSC.

The FCF Ground Segment interfaces with other ground facilities at NASA/GRC and at the PI remote sites:

- PI Remote Sites: PIs will be able to operate their experiment from their own site (typically at their university). They will be able to receive data and initiate commands just as though they were located at GRC, MSFC, or any other NASA centers. The PIs will receive the Telescience Resource Kit (TReK) from TSC. TReK is a PC-based command system that will allow PIs to monitor and control experiments located on-board the ISS from any PI remote sites in the World. PI remote sites will easily pay for themselves by reduced travel costs and increased science (because the PIs will be surrounded by their own experienced science staffs). The PI sites should not require staffing by FCF personnel due to the simplicity and fail safe nature of system.
- Telescience Support Center (TSC): The FCF operations team will be based at the TSC, NASA/GRC, building 333. The TSC contains a complement of Enhance HOSC System (EHS) sufficient to operate the FCF. During the mission, the operations team will work closely with the PI and his/her associates. The team will operate FCF at the direction of the PI and handle all hardware issues and interface issues with other NASA Centers and ISS; thus, the PI will be free to concentrate on maximizing the scientific return of the experiment. The PIs and the FCF operations team will be in constant contact via TReK to EHS.
- Data Storage: The vast bulk of FCF data will be sent to the earth in near real time (versus recording on permanent media for later return from ISS). Both the TSC and PI remote sites will receive the scientific data which can be in the form of raw or processed images, sensor reading, etc. The PIs will, therefore, have data from each experiment test point which they can use to plan the next point, if they desire. All the down-linked data will be automatically stored at the TSC, NASA/GRC for a minimum of 90 days.
- Data Archive: The data archive is located at NASA/GRC. The Flight Segment data received by TSC will be archived for a ten year period. This capability will allow the approved requesters access to data.

The following figure illustrates the distributed nature of the FCF ground segment. Most of the equipment will be located at GRC and GRC will operate FCF at the PI's direction. PIs will work at their home institutions assisted by their own staffs.

Telescience Hub Operations Concept



The concept of remote telescience with full command from the PI site through the GRC Telescience Support Center to MSFC and, ultimately the Space Shuttle was proven on STS-75. On that flight, the GRC IDGE experiment, was operated by the PI from Rensselaer Polytechnic Institute in Troy, NY.

1.5 Science Capability

The work of thousands of scientists and engineers is expected to benefit either directly or indirectly from experiments run in the FCF. For clarity, these technologists can be described as belonging to different groups (although a given technologist could belong to all of them). The groups and their relationship to FCF are explained in what follows.

Fluids and Combustion Engineering Communities: These world-wide communities of technologists create the products that the world buys; thus, they are FCF's link to the taxpayers. Although members of this group do not routinely follow microgravity science developments, they will incorporate the latest state-of-the-art into their products when appropriate. Membership of these communities probably numbers in the tens of thousands.

Fluid Physics and Combustion Science Scientific Communities: This community of scientists and engineers works to advance the state-of-the-art in their disciplines. These communities follow all relevant scientific developments including microgravity science developments. However, most of these investigators do not directly participate in microgravity science. Membership of these communities probably numbers in the thousands.

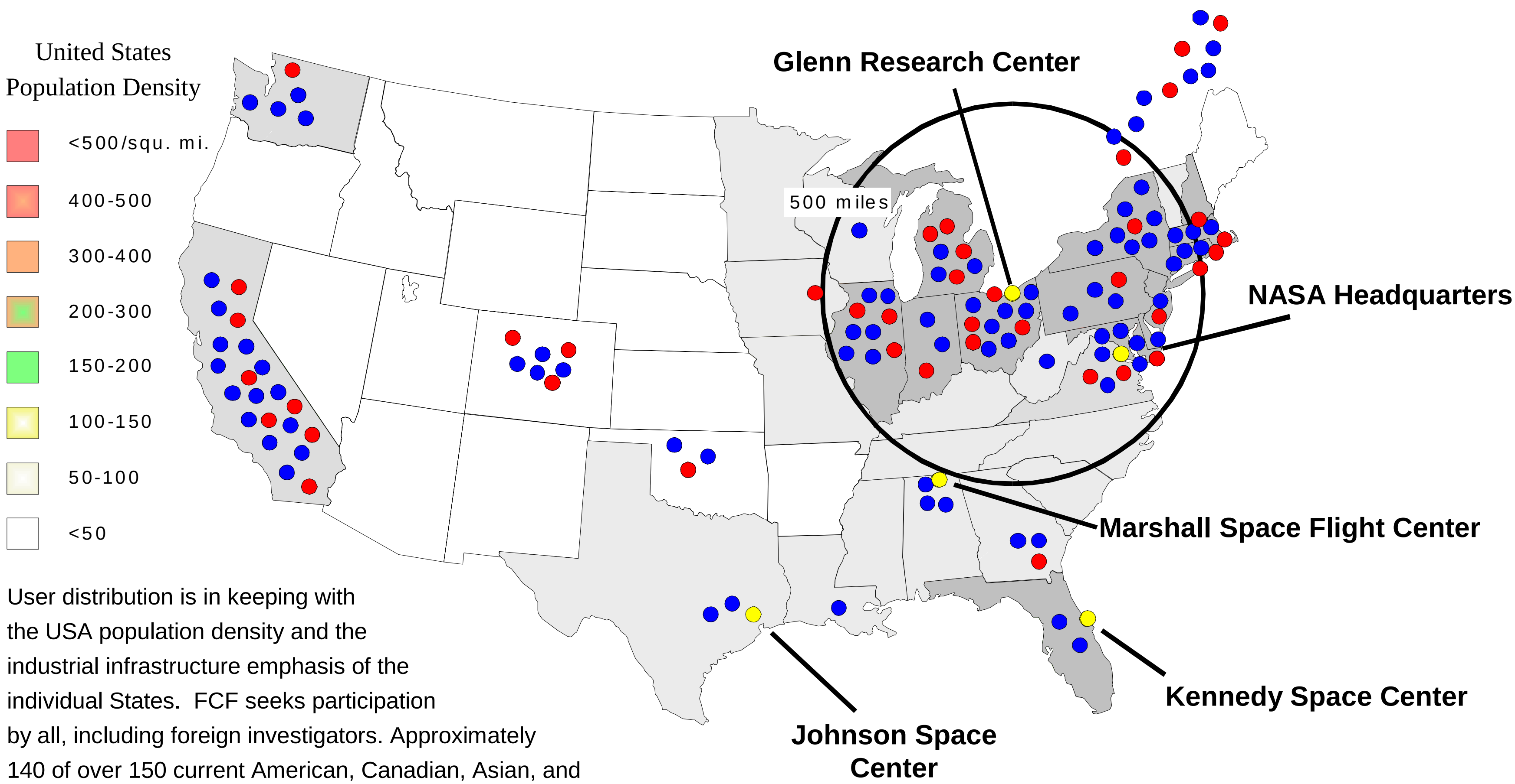
Microgravity Fluid Physics and Combustion Science Scientific Communities: These communities are a subset of the forgoing community. These communities advance their disciplines by making direct use of microgravity science data; however, not all of them create that data. Membership of these communities numbers one to two thousand.

Microgravity Fluid Physics and Combustion Science Ground Investigators: These investigators are a subset of the forgoing group. They specialize in microgravity experiments using, typically, microgravity aircraft and microgravity drop towers. Many of them have a goal of eventually being accepted as a Principal Investigator (PI). In the United States, Ground Investigators are funded by NASA and industry. Every two years, NASA receives approximately 400 formal experiment proposals from would-be Ground Investigators. Due to funding limitations, only one or two dozen can be accepted. United States Ground investigators currently number over 150.

Microgravity Fluid Physics and Combustion Science Principal Investigators (PI): These are investigators whose experiments have been formally selected to fly on Spacelab or ISS. Selection typically involves three or more years as a Ground Investigator followed by rigorous Peer review of the proposed experiment. The experiment must be highly valuable to the larger communities and must require long duration microgravity for success. Currently, United States fluids and combustion PIs number about thirty. Less than a dozen fly each year.

The following figure depicts the geographical distribution of the fluids and combustion scientists currently in the microgravity program.
Although some of these scientists are flight PIs, the majority are ground investigators competing for a flight opportunity. Every 2 years an additional 400 scientists compete to become ground investigators through NASA Research Announcements (NRA).

Geographical Distribution of FCF Scientist Users



User distribution is in keeping with the USA population density and the industrial infrastructure emphasis of the individual States. FCF seeks participation by all, including foreign investigators. Approximately 140 of over 150 current American, Canadian, Asian, and European competitively accepted scientists are depicted.

1.5.1 PI-specific Hardware

The hardware required to conduct specific science experiments within the FCF is defined as PI Specific Hardware. The FCF will implement an infrastructure to support the PI in every development phase necessary to achieve positive science results aboard the ISS.

The FCF PI support infrastructure will support the design, development, fabrication, test and evaluation, integration, launch, and operation of all PI-specific hardware. PI-specific Hardware includes hardware that mounts into the CIR chamber; experiment packages, which attach to the FIR and contain fluids; and various support hardware such as specific optics and electronics boxes. The support infrastructure will remain in place for the mission life of the FCF.

PI Support Infrastructure

The PI Support Infrastructure is comprised of the following:

- *Management* - The FCF management will concurrently support the development of 20-40 PI specific payloads.
- *Ground/Air Transportation* - Commercial ground and air cargo shipping services will be used to transport hardware from PI developer sites to GRC and from GRC to Kennedy Space Center (KSC).
- *Space Transportation* - Transportation of PI specific hardware will be managed by FCF and scheduled according to the ISSP integration process.

1.5.2 Technical Approach

The PI Support Infrastructure consists of two primary modes of support:

- Design, Fabrication, Verification and Turnover
- Utilization

Design, Fabrication, Verification & Turnover

The design component provides support in:

- Analysis (structural, thermal, and electrical)
- Manufacturing (piece parts, assembly, in-process tracking)
- Test & inspection
- Turnover process and procedures

The design infrastructure will allow designers, engineers, analysts and team leaders to work with PIs to produce efficient state-of-the-art components.

Utilization

The Utilization component provides support in:

- Analytical Integration
  - Mission Planning
  - Hardware Integration
- Operations
- Logistics
  - Hardware tracking
  - Maintenance
  - Packaging, Handling, Storage and Transportation
  - Science data delivery

Analytical Integration

Analytical Integration is the full spectrum of ISS requirements definition, interface definition resource allocation and negotiations, scheduling, integration and launch of hardware.

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Mission Planning

Mission planning includes scheduling of transportation to GRC and to the launch site, and launch vehicle manifesting.

Hardware Integration

ISS Hardware Integration includes launch site interface and presence. This effort overlaps with GRC verification and turnover.

Operations

ISS operations includes ISS interface requirements definition, scheduling, and real-time support. This effort overlaps with analytical integration.

Logistics

All sustaining engineering and support is contained in this effort.

Hardware Tracking

All PI flight hardware will be tracked while it is under FCF project control. A logistics database will maintain the history of the materials and components as required for ready reference during on-orbit operations.

Maintenance

FCF will coordinate and support repairs of PI hardware while it is under control of the FCF project.

Packaging, Handling, Storage and Transportation

FCF will provide or arrange for all of these elements at all locations while PI hardware is under control of the FCF project.

Science Data and Samples Delivery

Data will be provided to the PIs electronically during the course of the mission. Samples recovered will be shipped to the PI following deintegration from the return logistics carrier.

1.5.3 Manufacturing

An "assembly line" concept to manufacture will be employed, where designs are quickly, manufactured, integrated, and verified. Modifications to this process will be initiated to accommodate specific PIs and their hardware.

1.5.4 Verification

Verification of the PI Hardware interface with the FCF Flight Segment element will be performed by integrating the PI Hardware into the GIU for testing prior to launch. Modification to this process will be initiated to accommodate specific PIs and their hardware.

1.5.5 Safety

The PI specific hardware safety process will be integrated in to the FCF safety process. A dedicated section within the FCF Safety Data Package will define each new group of PI Specific Hardware. The FCF portion of the SDP will be updated to reflect changes resulting from the PI Specific Hardware. The FCF safety team will support Safety Reviews. All safety verifications of PI Specific Hardware will be coordinated by the FCF Safety Team.

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1.6 Other Requirements

Other requirements are based upon ISSPO, MRPO, GRC, MSD and Project directives. Such requirements include the accommodation of SAMS II, middeck payloads, support of fluids and combustion FCF payloads within the FCF, and processes and procedures governing the development of space flight hardware destined for ISS. These requirements originate from a broad spectrum of Management Instructions, Program and Project Plans, Program Specifications, and Directives.

Other requirements are derived from the Systems Engineering process. These include Facility and Integrated Rack architecture, requirements definition, requirements decomposition, characteristics, capabilities, interchangeability, commonality, allocation of resources, maintenance, reliability, logistics, scarring, upgrades, verification, flexibility and modularity and other requirements necessary to meet resource constraints and science mission. These requirements are captured by the *Fluids and Combustion Facility, Type A, System Specification*, FCF-SPEC-001; the *CIR Type B, Prime Item Development Specification*, FCF-SPEC-002; the *FIR Type B, Prime Item Development Specification*, FCF-SPEC-003; and the *SAR Type B, Prime Item Development Specification*, FCF-SPEC-004; and the Ground Segment Specification, FCF-SPEC-005.

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Chapter 2 – Reference Documents

2 REFERENCE DOCUMENTS

FCF Program Applicable Documents

Accepted and documented practices, methods, and materials–specifications and standards are used to the maximum extent practical. These practices, methods, and materials should be consistent with program objectives to provide a proven technical basis for, and to reduce the cost and technical risk of, system development and operations. A wide range of requirement documents, specifications, and standards are used to drive and control the FCF design, fabrication, test, shipping, and installation processes. The documents listed in the following tables provide the requirements, design guidance, and resource definition for the FCF. This list may be incomplete and will be updated as conditions warrant.

A preliminary list of the specifications and standards that are applicable to the FCF program is provided in the following tables.

System Requirements (Table 1 of 2)

Document Number	Document Title	Document Source
FCF-DOC-0002	Science Requirements Envelope Document	MSD
FCF-DOC-0004	Science Requirements Envelope Document – Compliance Matrix	MSD
FCF-SPC-0001	System Specification – ISS Fluids and Combustion Facility	MSD
FCF-SPC-0002	CIR Prime Item Development Specification	MSD
FCF-SPC-0003	FIR Prime Item Development Specification	MSD
FCF-SPC-0004	SAR Prime Item Development Specification	MSD
CIR-IDD-0046	CIR Interface Definition Document	MSD
FIR-IDD-0137	FIR Interface Definition Document	MSD
NSTS 07700 Vol. XIV	Space Shuttle Payload Accommodations Handbook	NASA
NSTS 15046	Payload Verification Requirements	NASA
SSP 41017	Rack to Multi-purpose Logistics Module Interface Control Document (ICD) Part 2	ISS
SSP 41152	Interface Requirements Document – International Standard Payload Rack	ISS
SSP 41170	Configuration Management Requirements	ISS
SSP 41171	Preparation of Program-unique Specifications	ISS
SSP 50200-03	Station Program Implementation Plan, Vol. III, Cargo Integration	ISS
SSP 50200-04	Station Program Implementation Plan, Vol. IV, Payload Integration	ISS
SSP 57000	Pressurized Payloads Interface Requirements Document	ISS
SSP 57001	Pressurized Payloads Hardware Interface Control Document Template	ISS
SSP 57002	Pressurized Payloads Software Interface Control Document Template	ISS
SSP 57010	Pressurized Payloads Generic Payload Verification Plan	ISS
SSP 57020	Pressurized Payloads, Payload Accommodations Handbook	ISS

System Requirements (Table 2 of 2)

Document Number	Document Title	Document Source
SSP 57117	FCF Payload Integration Agreement	ISS
SSP 57217	CIR/ISS Hardware Interface Control Document	ISS
SSP 57218	FIR/ISS Hardware Interface Control Document	ISS
SSP 57219	SAR/ISS Hardware Interface Control Document	ISS
SSP 57317	CIR/ISS Software Interface Control Document	ISS
SSP 57318	FIR/ISS Software Interface Control Document	ISS
SSP 57319	SAR/ISS Software Interface Control Document	ISS

Design

Document Number	Document Title	Document Source
ANSI Y14.5M	Dimensioning and Tolerancing Standard	Industry
DOD-D-1000	Drawings, Engineering, and Associated Lists	Military
DOD-STD-100	Engineering Drawing Practices	Military
DOD-STD02167	Defense System Software Development	Military
MIL0HDBK-5	Metallic Materials and Elements for Aerospace Vehicle Structures	Military
MIL-STD-1686	Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies, and Equipment	Military
MSFC-HDBK-527/JSC 09604	Materials Selection list for Space Hardware Systems	NASA
MSFC-SPEC-522	Design Criteria for Controlling Stress Corrosion Cracking	NASA
MSFC-STD-1249	NDE Guidelines and Requirements for Fracture Control Programs	NASA
NASA-STD-6001	Flammability, Odor, Off-gassing, and Compatibility Requirements and Test Procedures for Materials in Environments that Support Combustion	NASA
NHB 5200.4 (3K)	Design Requirements for Rigid Printed Wiring Boards and Assemblies	NASA
NHB 8060.1	Flammability, Odor, and Off-gassing Requirements and Test Procedures for Materials in Environments that Support Combustion	NASA
SP-R-0022	General Specification Vacuum Stability Requirements for Polymeric Material for Spacecraft Application	NASA
SSP 30233	Space Station Requirements for Materials and Processes	ISS
SSP 30558	Fracture Control Requirements for SSP	ISS
SSP 30559	Structural Design and Verification Requirements	ISS

Electrical/Electronic

Document Number	Document Title	Document Source
MIL-HDBK-1553	Multiplex Application Handbook	Military
MIL-STD-454	General Requirements for Electrical Equipment	Military
MIL-STD-975	NASA Standard Electrical, electronic, and Electromechanical (EEE) Parts list	Military
MIL-STD-1553	Digital Time Division Command/Response multiplex Data Bus	Military
SSP 30237	Electromagnetic Emission and susceptibility Requirements for EMC	ISS
SSP 30238	Electromagnetic Techniques	ISS
SSP 30240	Space Station Grounding Requirements	ISS
SSP 30243	Requirements for Electromagnetic Compatibility	ISS
SSP 30245	Electrical Bonding Requirements	ISS

Safety

Document Number	Document Title	Document Source
KHB 1700.7	Payload Ground safety Requirements Handbook	NASA
MIL-STD-882	System Safety Program Requirements	Military
NHB 1700.1 (V1-B)	NASA Safety Policy and Requirements Document	NASA
NMI 1710.3	Safety Program for Pressure Vessels and Pressurized Systems	NASA
NSTS 1700.7	Safety Policy and Requirements for Payloads Using the international Space Station	NASA
NSTS 13830	Implementation Procedure for NSTS Payload System Safety Requirements	NASA
SSP 30309	Safety Analysis and Risk Assessment Requirements	ISS
SSP 30599	Space Station Safety Review Process	ISS

Reliability/Maintainability

Document Number	Document Title	Document Source
SSP 30234	Instructions for Preparation of FMEA and CIL for Space Station	ISS

Quality Assurance

Document Number	Document Title	Document Source
DOD-STD-2168	Defense System Software Quality Program	Military
MIL-HDBK-6870	Inspection Program Requirements, Nondestructive for Aircraft and Missle Materials and Parts	Military
SSP 41173	Space Station Quality Assurance Requirements	ISS

Logistics

Document Number	Document Title	Document Source
MIL-STD-1388-1	Logistics Support analysis	Military
MIL-STD-1388-2	DOD Requirements for a Logistics Support Analysis Record	Military
SSP 50200-05	Station Program Implementation Plan, Vol. V, Logistics and Maintenance	ISS
SSP 50200-06	Station Program Implementation Plan, Vol. VI, Launch Processing	ISS

Operations/Utilization

Document Number	Document Title	Document Source
SSP 50011-01	Concept of Operations and utilization, Vol. 1, Principles	ISS
SSP 50200 Vol. 7	Station Program Implementation Plan, Vol. VII, Training	ISS
SSP 50200 Vol. 8	Station Program Implementation Plan, Vol. VIII, Increment Execution Preparation	ISS

Manufacturing/Assembly

Document Number	Document Title	Document Source
MIL-HDBK-263	Electrostatic Discharge Control Handbook for Protection of Electrical and Electronic Parts, Assemblies, and Equipment	
NASA-STD-8739.3	Soldered Electrical Connections	NASA
NASA-STD-8739.4	Crimping, Interconnecting Cables, harness, and Wiring	NASA
NASA-STD-8739.5	Fiber Optic Terminations, Cable Assemblies, and Installation	NASA
NHB 5300.4 (3H)	Requirements for Crimping and Wire Wrap	NASA
NHB 5300.4 (3I)	Requirements for Printed Wiring Boards	NASA
NHB 5300.4 (3J-1)	Requirements for Conformal Coating and Staking of Printed Wiring Boards and Electronic Assemblies	NASA

Cleanliness Control

Document Number	Document Title	Document Source
MIL-STD-1246	Product Cleanliness levels and Contamination Control Program	Military
SN-C-0005	NSTS Contamination Control Requirements Manual	NASA

Testing

Document Number	Document Title	Document Source
MIL-STD-810	Environmental Testing Methods and Engineering Guidelines	Military
SSP 3-695	Acceptance Data Package Requirements Specification	ISS
SSP 41172	Space Station Qualification/Acceptance Environmental Test Requirements	ISS

Pack/Packaging/Shipping

Document Number	Document Title	Document Source
MIL-P-116	Preservation, Methods of	Military
MIL-STD-129	Marking for Shipment and Storage	Military
MIL-STD-130	Identification Marking of U.S. Military Property	Military
MIL-STD-2073	DOD Material Procedures for Development and Application of Packaging Requirements	Military
NHB 6000.1	Requirements for Packaging, Handling, and Transportation for Space Systems, Equipment, and C0mponents	NASA

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Chapter 3 – ISS Resources/Services

3.0 ISS Resources/Services

The FCF racks are designed to utilize standard ISS services and route them to the PI for experiment use. Several services have options, such as the temperature range of the cooling loop, or the type of gas service supplied. The following pages detail each of these services and their benefit to the payloads.

The available ISS services and FCF requirements are listed in the following table.

ISS Services and FCF Requirements (Table 1 of 2)

SERVICE CATEGORY	SERVICE or RESOURCE	US LAB CAPABILITY	FCF REQUIREMENTS	COMMENTS
Mechanical	International Standard Payload Rack (ISPR)	Various styles	ISPR-4	FCF requires 4-post rack configuration
	Active Rack Isolation System (ARIS)	Available for each rack	Required	ARIS attenuates low frequency (<100 Hz) on-orbit vibrations
Power	Main power circuit	3 KW, 120 VDC, 25 Amp	2.6 KW max	Station provides a non-current limiting feed
	Auxiliary power circuit	1.44 KW, 120 VDC, 12 Amp	Not required	Station provides a current limiting feed
	Utility outlet panel	28 VDC	Not currently planned	Can use for laptop computer
Data Management	Communication and Tracking (C&T) System			
	• Audio	Multi-channel, multi-access, full duplex	Not required	
	• Video	Pulse Frequency Modulation (PFM) fiber optic	Required	FCF will transmit analog video to ground sites
	Command and Data Handling (C&DH) System			
	• Low rate data line	1553 B Bus	Required	Used for command, health, and status data
	• Medium rate data line	10 Base T Ethernet LAN	Required	Used for inter-rack communications and transmittal of telemetry
	• High-rate data line	Fiberoptic data distributed interface	Required	Used to transmit digitized, real-time video

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ISS Services and FCF Requirements (Table 2 of 2)

SERVICE CATEGORY	SERVICE or RESOURCE	US LAB CAPABILITY	FCF REQUIREMENTS	COMMENTS
Fluids and Gases	Low temperature cooling	100 – 890 lb/hr 3.33°C - 5.55°C (38°F - 42°F)	Not required	
	Moderate temperature cooling	100 – 745 lb/hr 16.1°C - 18.5°C (61°F - 65°F)	100 – 265 lb/hr @ 18.3°C (65°F)	
	Nitrogen, Argon, Carbon Dioxide, Helium	75 – 120 psia 15.6°C - 45°C (60°F - 113°F)	Nitrogen only	Flow of N_2 into rack not to exceed 12 lbm/hr
Thermal	Internal Thermal Control System (ITCS)	13.0 KW max	2.6 KW	Heat rejection indicated Interface through cold plate.
Vacuum and Venting	Vacuum Exhaust System (waste gas vent)	40 psia, max	40 psia, max	Can accept gases at 15.6°C - 45°C (60°F - 113°F) and at a dew point of (60°F) or less
	Vacuum resource system	- -	As provided	May access after the PI package reaches 1×10^{-3} torr
Fire Detection/ Suppression	Fire Detection	Smoke detector	As provided	
	Fire Suppressants	CO_2	As provided	ISS can also vent module to space vacuum

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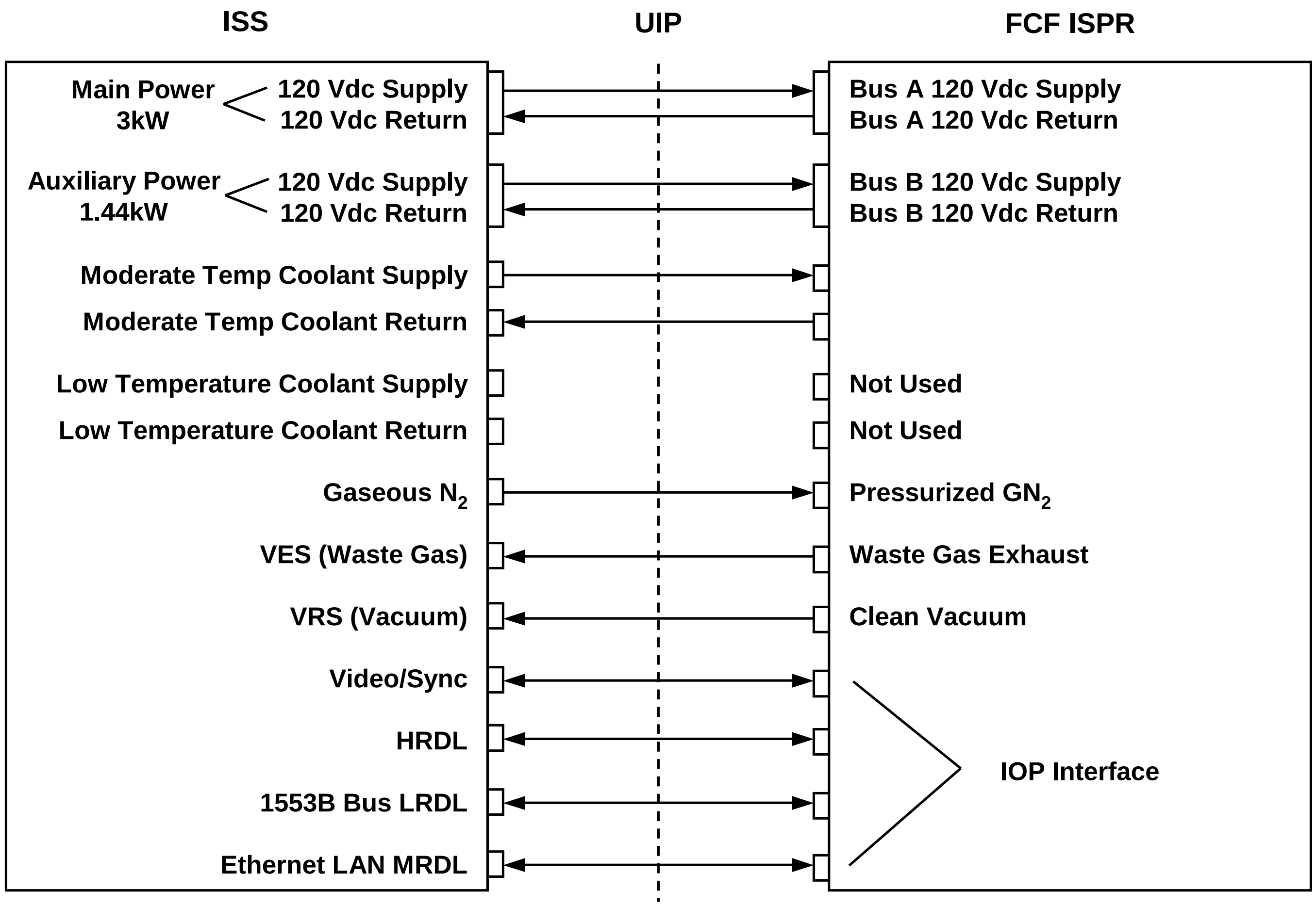
The Utilities Interface is shown in the following figure.

ISS/FCF ISPR Utilities Interface



3.1 Structure

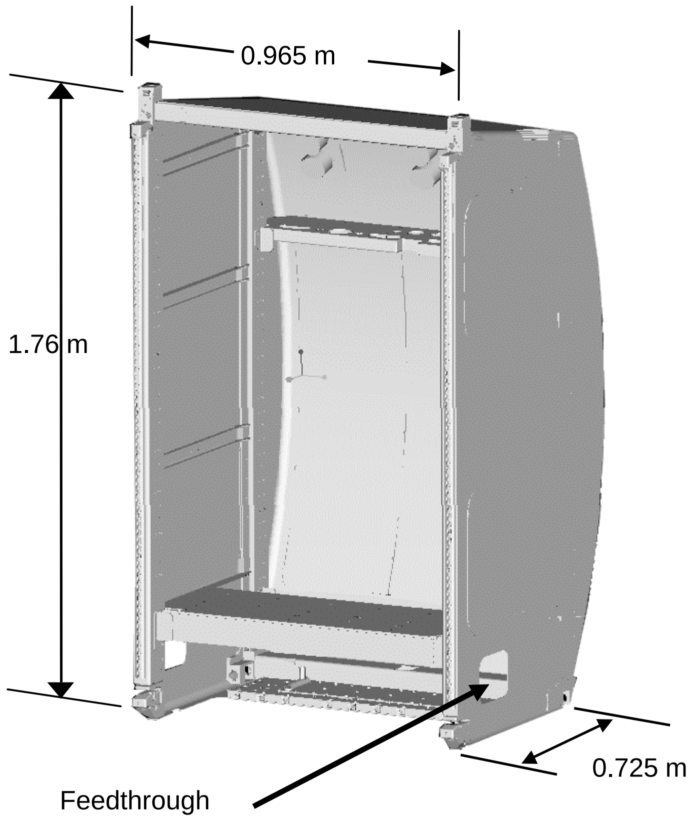
The basic module structure of the United States Laboratory (U.S. Lab) Module of ISS in which FCF will be located consists of a cylinder section, debris shield, endcones, and standoffs. Four sets of standoffs inside the pressure shell provide structural support for the racks, and utility routing to the racks. The structural resources provided by the ISS for the FCF include an International Standard Payload Rack (ISPR) and an Active Rack Isolation System (ARIS).

The NASA ISPR is the basic structure for payload equipment and is mounted on-orbit to an ISPR location. The ISPR is essentially an empty shell that houses all the payload equipment. For the FCF, the ISPR will be a 4-post configuration designated as a "dash 4" (–4) ISPR. Each post of the NASA ISPR includes provisions for mounting payload equipment. Mounting patterns are repeated on all posts. Each –4 ISPR location provides standard mechanical attachments and a stand-off-mounted Utility Interface Panel (UIP) for access to the station-provided utilities. Payload racks connect to the module utilities at the UIP.

The –4 ISPR can accommodate an ARIS, which will ensure the microgravity environment required by science. The ARIS is designed to isolate an ISPR and its payload by attenuating on-orbit low frequency (<100 Hz) mechanical vibrations that can be transmitted from the U.S. Lab Module to the FCF when the experiments are conducted.

The ISS rack structure is pictured in the following figure

ISS Structural Interface



3.2 Power

Utilities Interface

The U.S. Lab Module provides the following power utilities:

- One 120 Vdc, 3 kW, 25 amp **main power feed**
- One 120 Vdc, 1.44 kW, 12 amp **auxiliary power feed**
- Six **utility outlet panels** (UOP) to provide power and data connections for use by portable equipment

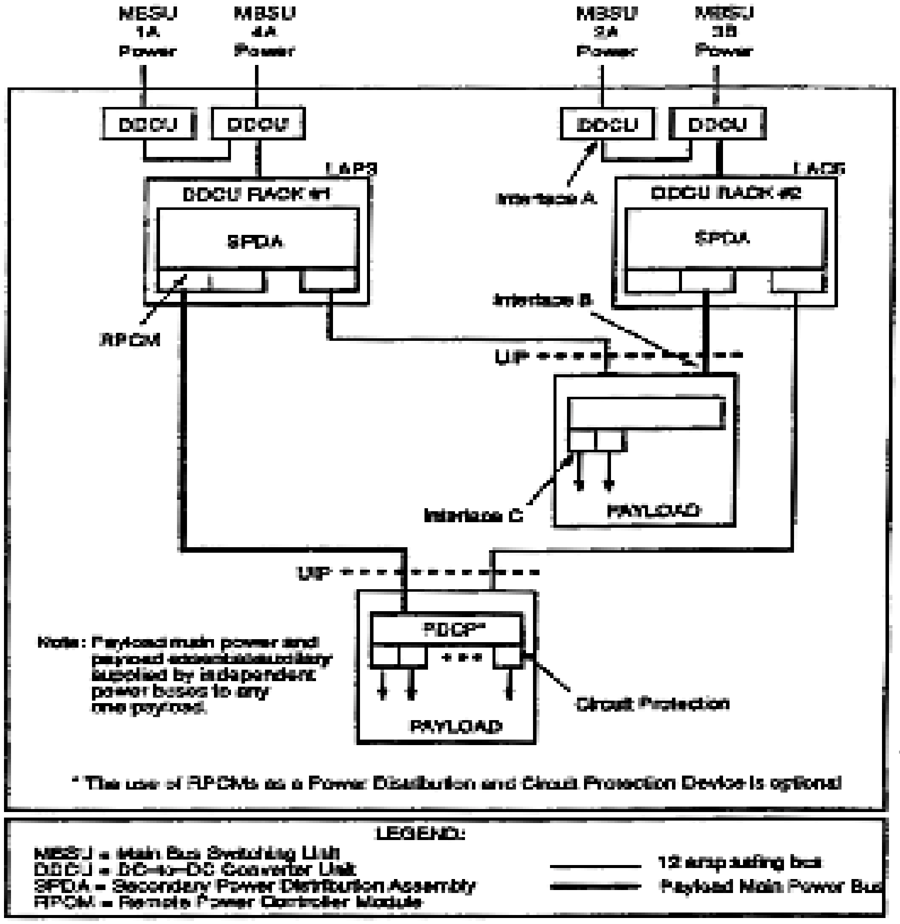
Power Interface

The power that is provided to each ISS ISPR interface is 120V-dc steady state. Each 3 kW and 6 kW ISPR location is supplied by one main (Interface A) and one auxiliary/essential (Interface B) power feed. Each power feed comes from an independent power source. The FCF is limited by the power available at a rack location, and it is also constrained by the ISS-provided ability to reject the heat that results from the utilized power.

Interface B will provide the primary ISS power interface for the FCF. **Interface A** is defined as the power output at a Direct-Current-to-Direct-Current Converter Unit (DDCU). Interface C is defined as the power output from Remote Power Controller Modules (RPCM).

The ISS power system and how it interfaces with the payload are shown in the following figure.

ISS Power Interface



3.3 Data Management

Communications and Tracking (C&T)

A Communications and Tracking (C&T) system is a collection of functions that provide for the exchange of audio, video, and data. The C&T system is composed of the Global Positioning Subsystem, Video distribution System, Audio Distribution System, Ultra-high Frequency System, S-band System, and Ku-band System. The Audio Distribution Subsystem provides a multi-channel, multi-access, full duplex audio inter-communication network on board the Station.

The Video Distribution Subsystem provides the generation, distribution, and display capabilities of video images onboard the ISS. An audio distribution interface is not currently available or required at the CIR (and FCF) racks.

Command and Data Handling (C&DH)

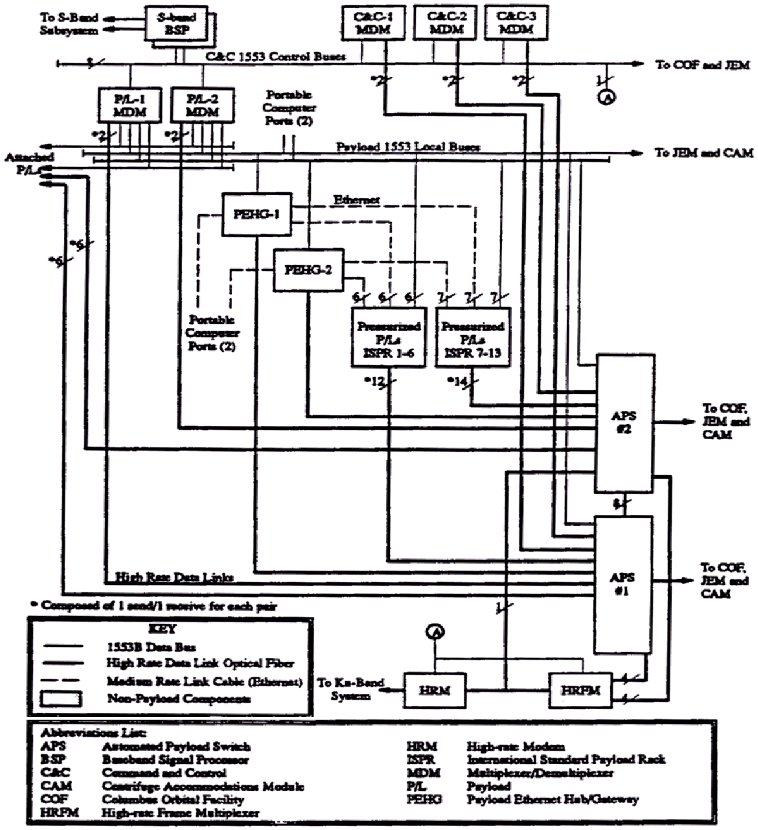
A **Command and Data Handling** (**C&DH**) function consists of the hardware and the software that are required to communicate, command, and control all station systems, subsystems, and payloads. The Command and Control (C&C) Multiplexer/ Demultiplexers (MDMs) are required for command, control, and data distribution. The C&DH includes low, medium, and high-rate data lines (LRDL, MRDL, and HRDL, respectively).

Payload local buses are connected to the control buses via Payload MDMs for command, control, and data distribution to the lower level payload processors and payload support equipment (such as, Automated Payload Switch (APS) and Payload Ethernet Hub/Gateway). One High-rate Data Link (HRDL) is provided for payload complement utilization for passing data to the Communication and Tracking (C&T) system for telemetering to the ground. High-rate payload-to-payload communications may be accomplished through use of the HRDLs.

C&DH provides several services for payloads, particularly in the area of command and control. These services include but are not limited to payload displays and controls, data transfer, health and status monitoring, automated procedure execution, and caution and warning detection and annunciation.

The US Lab Command, and Data Handling (C&DH) System is shown in the following figure.

C&DH Architecture



3.4 Thermal Control

The U.S. Lab Module provides interfaces to the following services:

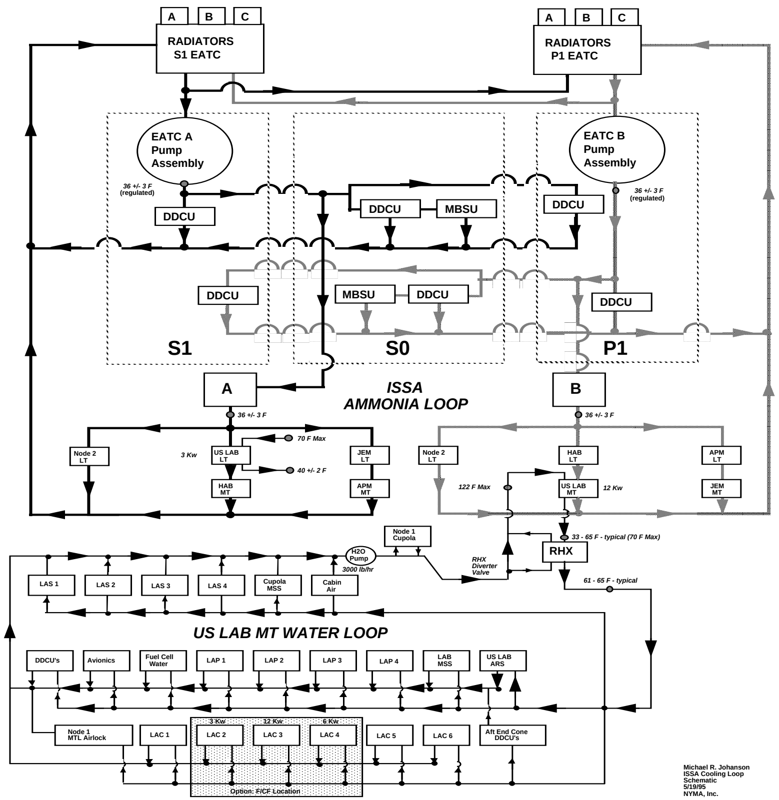
- The **Internal Thermal Control System** (**ITCS**) **loops** are pumped, single-phase water loops that collect waste heat from subsystem and payload equipment within the modules and transport the waste heat to Central Thermal Bus (CTB) heat exchangers. The U.S. Lab Module contains a Low Temperature (LT) loop and a Moderate Temperature (MT) loop which can reject a total of 13.0 kW for all payloads.

- The **Low Temperature Coolant** will not be used by FCF. The Moderate Temperature Coolant Water is supplied at a temperature of 16.1°C to 18.3°C (61°F to 65°F), and a flow rate of 45 to 339 kg/h (100 to 745 lb/h).

- **Gaseous nitrogen** (**GN_2**), carbon dioxide (CO_2), helium (He), and Argon (Ar) are provided by the Environmental Control and Life Support Systems at each ISPR location in the U.S. Lab Module. FCF will use only the gaseous nitrogen. Access to nitrogen is controlled using a manual-shutoff quick-disconnect valve at the ISPR location Utility Interface Panel (UIP). Nitrogen gas is available at 517 kPa to 827 kPa (75 to 120 psia) and 15.6°C to 45.0°C (60°F to 113°F).

The US Lab Internal Thermal Control System is shown in the following figure

U.S. Lab Module ITCS



3.5 Gas Interface

Gaseous nitrogen (**GN_2**), carbon dioxide (CO_2), helium (He), and Argon (Ar) are provided by the Environmental Control and Life Support Systems at each ISPR location in the U.S. Lab Module. FCF will use only the gaseous nitrogen. Access to nitrogen is controlled using a manual-shutoff quick-disconnect valve at the ISPR location Utility Interface Panel (UIP). Nitrogen gas is available at 517 kPa to 827 kPa (75 to 120 psia) and 15.6°C to 45.0°C (60°F to 113°F).

3.6 Vent Systems

The ventilation/vacuum services available to the FCF include:

- A shared resource **vacuum exhaust system/waste gas vent interface** (Table 3-2) provides for removing (disposal) non-toxic and non-reactive waste gases from one payload at 40 psia max. (280 kPa). The waste gas vent is shared with other U.S. Lab payloads.
- The **vacuum resource system/vacuum vent system** is available at nine ISPR locations (ceiling and starboard) in the U.S. Lab Module to provide long duration clean vacuum. A payload accesses the vacuum through a manual-shutoff quick-disconnect valve connected to the utility interface panel at each of the nine locations. A payload may access the vacuum resource system through the waste gas vent system after reaching $1x10^{-3}$ torr. The vacuum resource system will also carry leakage gases and offgassed gases away from the experiment chamber to maintain vacuum.

3.7 Fire Detection and Suppression

The primary form of fire protection is to prevent the occurrence of fire through proper material selection and appropriate design criteria, including wire derating/fusing.

Fire detection and suppression capabilities include a Station-provided fire alarm and a smoke detector. Fires can be suppressed by introducing a station-provided fire extinguisher containing a carbon dioxide fire suppressant or by venting the module atmosphere to space vacuum

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3.8 Trash Management

A housekeeping/trash management subsystem is a Station-provided service that provides for routine cleaning and trash management of the module interior. Portable trash receptacles are provided for the temporary storage of acceptable trash and payload waste.

3.9 Atmosphere

The U.S. Lab's atmosphere is actively controlled and conditioned by the Environmental Control and Life Support System (ECLSS). Carbon dioxide control is provided to prevent a build-up of CO_2 from metabolic sources to levels that would be hazardous to human life. Also, levels are maintained to provide an environment suitable for research.

3.10 Utility Outlet Panel

Six Utility Outlet Panels (UOPs) provide power and data connections for the portable equipment in the U.S. Lab Module. Each UOP contains one Ground Fault Circuit Interrupt (GFCI) to protect both outlets.

3.11 Electrical Grounding and Isolation

Payloads equipment and subsystems will meet the grounding and isolation requirements of SSP 30240 including but not limited to the single point ground and isolation requirements for secondary, tertiary, equipment conditioned power, and signal return circuits.

3.12 Electrical Bonding

The bond path from the payload electrical equipment to the structure goes from the payload equipment box surface interface and through the nickel-plated mounting surfaces at two locations on the rack. Bonding for ARIS racks is accomplished through the use of a mesh strap that is provided as part of the ARIS standard umbilical assembly.

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Chapter 4 - System Description

4 FCF SYSTEM DESIGN

4.1 FCF Assembly Sequence

The Fluids and Combustion Facility Flight Segment will be deployed to the ISS incrementally. The ***Initial Deployment*** is the Combustion Integrated Rack (CIR) launched on UF-3. The ***Intermediate Deployment*** consists of the Fluids Integrated Rack (FIR) launched on UF-5. The CIR and the FIR will operate independently until UF-7 at which point the SAR is added and the FCF is ***Fully Deployed***.

Prior to the deployment of the SAR, the CIR, and the FIR function as autonomous 'integrated' racks allowing for early combustion and fluid physics research opportunities on Station. The CIR and FIR physical envelope, mass and functional aspects limit the amount of experiments that can be accommodated within these integrated racks.

With the addition of the SAR and reconfiguration of the CIR and the FIR, assembly of the Fluids and Combustion Facility is completed. The fluid physics and combustion science disciplines then share the capabilities of the three FCF racks and necessary hardware within the FCF to accommodate the full fluid/combustion science envelope over the facility's ten-year, post-assembly complete life cycle.

4.2 Flight Segment

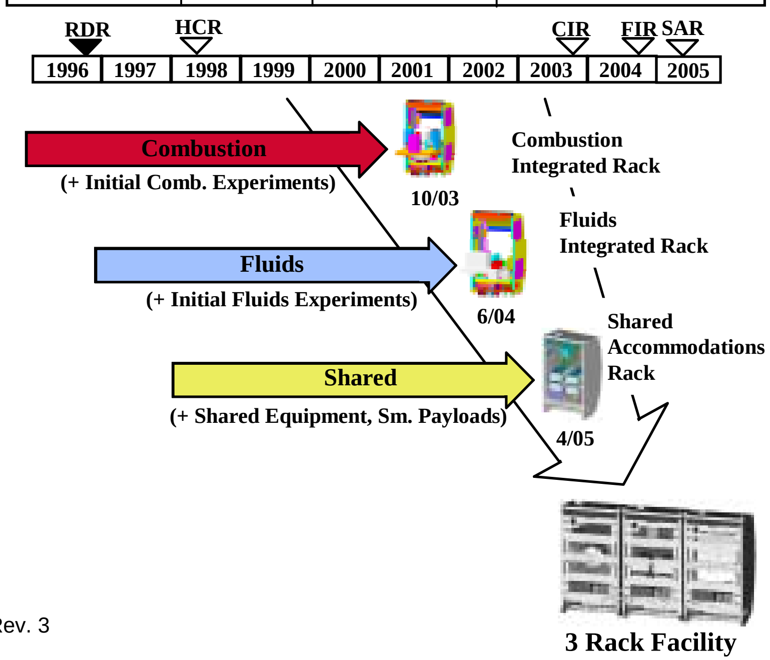
The FCF *flight segment* consists of the three powered rack facility plus one rack (or equivalent volume) of unpowered stowage located on the ISS.

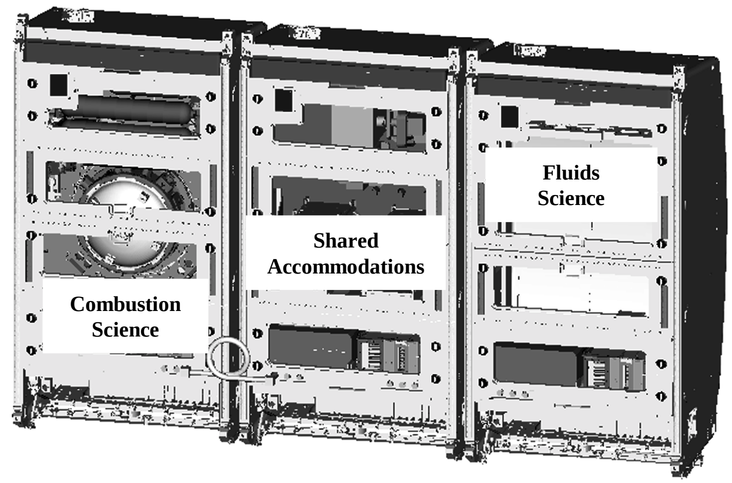
The following figure illustrates the FCF deployment scheme with a brief overview.

ISS Fluids and Combustion Facility

ISS Fluids and Combustion Facility - Deployment

After full deployment to ISS, the FCF must support 5-10 PI experiments per year in each science discipline, plus commercial and international users.	CIR	CIR FIR	Fluids and Combustion Facility
Deployment State	Initial Deployment (CIR Only)	Intermediate (CIR & FIR)	Fully-Deployed System (CIR, FIR & SAR)
Launch	UF-3	UF-5	UF-7
Operational Period	10/2003 to 6/2004 (8 months)	6/2004 to 4/2005 (10 months)	4/2005 + (10 years)
System Capability	Combustion Science	Combustion Science Fluids Science	Combustion Science Fluids Science Commercial/International Utilization Other ISS/Payload Systems Supported
PI Expt. Thru-put • Combusiton PI's • Fluids PI's • Commercial/Int'l.	2 PI/yr - -	2 PI/yr 2 PI/yr -	5-10 PI/yr 5-10 PI/yr Up to 10 PI/yr





FCF MISSION:
To Support Sustained, Systematic Microgravity Fluid Physics and Combustion Science On Board the International Space Station.

FACILITY DESCRIPTION:
The FCF Flight Segment Consists of Three Powered Racks Plus One Rack (or Equivalent Volume) of Unpowered Stowage Located on the ISS. The FCF Ground Segment Consists of Ground-Based Equipment at the GRC Telescience Support Center and PI Remote Sites Which Work With the Flight Segment During a Mission to Accomplish the Scientific Objectives.

OPERATIONS:

Primarily Teleoperated (Some Crew Time Needed for Set-Up/Tear-Down, Reconfiguration and/or Maintenance). Investigators Operate Experiments from Their Own Site via the GRC Telescience Hub.

UTILIZATION:
The Fluids and Combustion Facility Must Support at Least 10 Fluids and Combustion PI Experiments Per Year Plus Commercial and International Users During Its Nominal 10 Year Life on ISS.

4.2.1 Initial Deployment - Combustion Integrated Rack

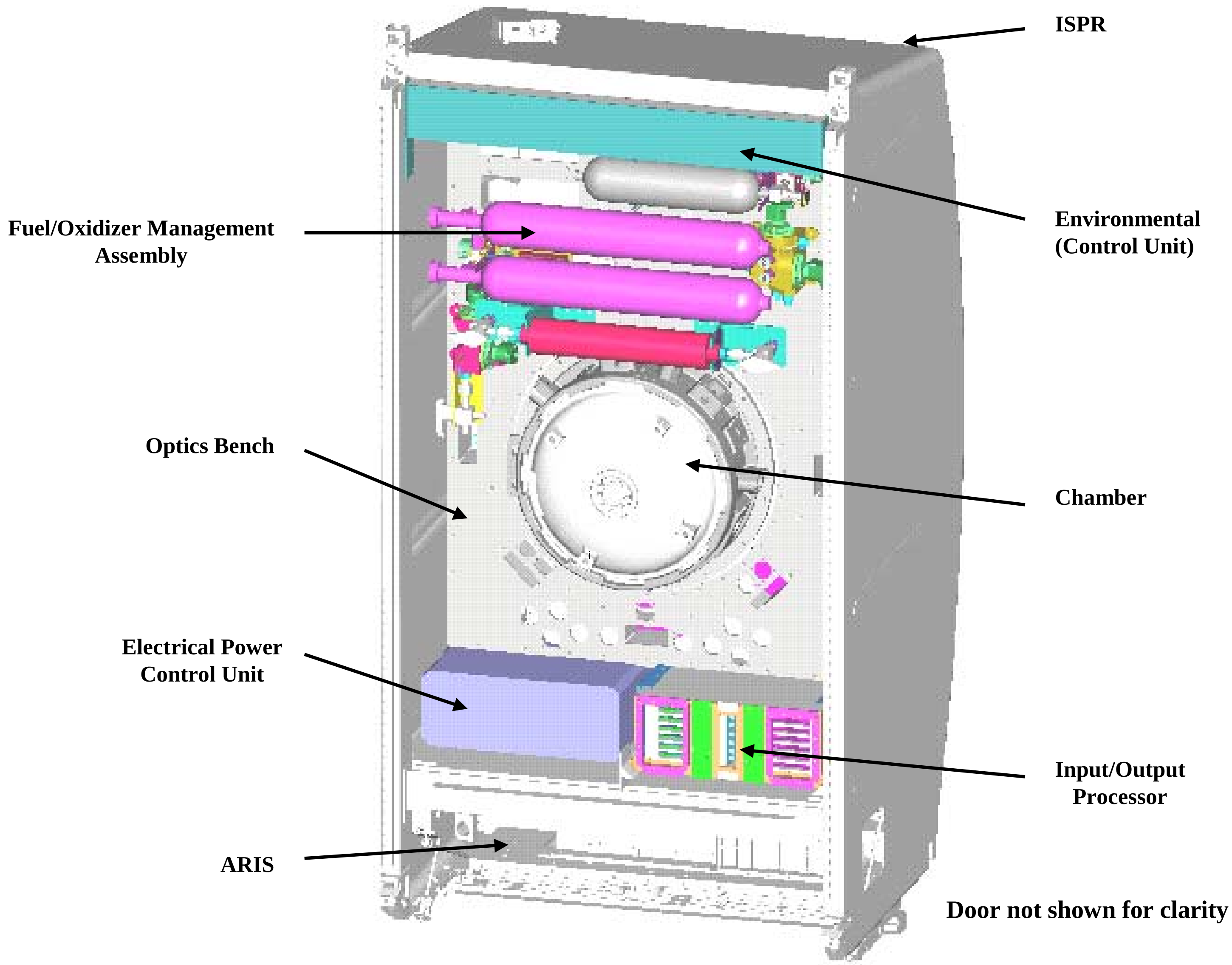
The Combustion Integrated Rack is the first FCF element launched and is currently scheduled to fly on Utilization Flight #3 (2/2002). The CIR provides sustained Combustion physics research in the microgravity environment of the ISS. Investigators use this microgravity environment to isolate and control gravity-related phenomena, and to investigate processes that are normally masked by gravity effects and thus are difficult to study on Earth. Combustion microgravity experiments can provide a unique insight into the control of the generation of combustion by-products (pollution) and the increase efficiency of fuels.

The CIR systems are as follows:

- Optics Bench
- Combustion Chamber
- Diagnostics
- Fuel Oxidizer and Management Assembly
- Exhaust Vent System
- Experiment Specific Hardware
- Structural/Mechanical (ISPR/Door/ARIS)
- Electrical Power System
- Environmental Control System
- Command and Data Management System (Input/Output Processor, Image Processing & Storage, Software, Laptop)

The following figure depicts the Combustion Integrated Rack with callouts

Combustion Integrated Rack (CIR)



4.2.2 Intermediate Deployment - Fluids Integrated Rack

The Fluids Integrated Rack is the second FCF element launched and is currently scheduled to fly less than a year after the CIR on Utilization Flight #5 (6/2002). The FIR will then join the CIR in single "integrated" rack operations. Paramount to the FCFs flexible design is the ability for the FIR and CIR to function independently as single 'integrated" racks allowing for early science research opportunities (accommodating ISS launch manifests) and maximizing early on-orbit opportunities when ISS resources may not support two/three rack operations.

The FIR is a modular; multi-user facility to accommodate a wide variety of microgravity fluid physics science experiments on-board the US Laboratory Module of the International Space Station (ISS). The unique, long-term, microgravity environment and long operational times on the ISS will offer experimenters the opportunity to modify experiment parameters based on their findings similar to what can be accomplished in ground laboratories. The FIR concept has evolved over time to provide a flexible, “optics bench” approach to meet the wide variety of anticipated research needs. The FIRs system architecture is designed to meet the needs of the fluid physics community while operating within the constraints of the available ISS resources.

The system architecture for a space station facility to perform fluid physics experiments has gone through various iterations to achieve the science needs and evolving space station vehicle accommodations. Direct interaction with fluid physics scientists, selection of an initial set of Principal Investigators, maturity of the ISS, and commonality with the CIR architecture has led to the current FIR concept.

The FIR concept is based on a “carrier” approach that provides common services needed by nearly all fluids physics researchers to minimize the hardware required to be developed and launched for each experiment. Since a majority of hardware is reused, the FIR concept saves both development costs and total upmass required to perform the experiments.

The FIR system derived from the science requirements and the ISS requirements has the following subsystems determined to be essential to perform the microgravity fluid physics experiments:

- Fluids Experiment Assembly
- Rotating bench Package
- Diagnostics
- Experiment Specific Hardware
- Structural/Mechanical (ISPR/Door/ARIS)
- Electrical Power Subsystem
- Environmental Control Subsystem
- Command and Data Management Subsystem (Input/Output Processor, Image Processing & Storage Units, Software, Laptop)

The facing figure provides a description of the Fluids Integrated Racks Features.

FCF Fluids Integrated Rack Features

FIR Features:

- Easy access via fold down bench
- 25 mm optics table hole pattern
- Diagnostics easily reconfigured,replaced/interchanged
- Accommodates many experiment configurations and disciplines

Image Processing Packages:

- High Speed Cameras - 1024 x 1024 12-bit pixels up to 60 fps (100 fps TBD)
- High Resolution Microscopic Camera -8x magnification for 2.6 mm x 2.6 mm field, 4 micrometer resolution
- Color Camera 484x768 pixels
- Ultra-High Frame Rate Camera (>100 fps) *TBD Availability*
- Data collection at 40 MB/sec

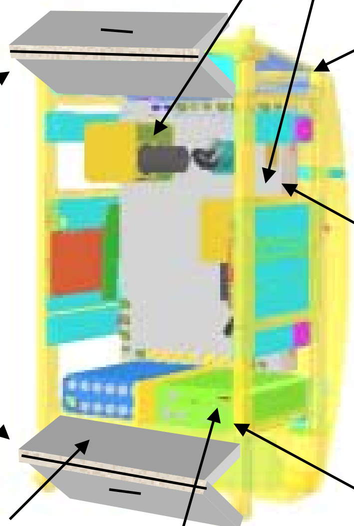
Optical Components:

- Lenses
- Collimators
- Fiber optic cables
- Mirrors
- Light sheet optics

Environmental Control:

Fans (2) and Radiator(s)

- 800W to 1600 W of air cooling available to PI Unique H/W
- 200 W Cold Plate(s) for PI in Plate
- 400 W of Water Cooling
- 18 C inlet - 48 C outlet TBR
- Rack Structural Augmentation

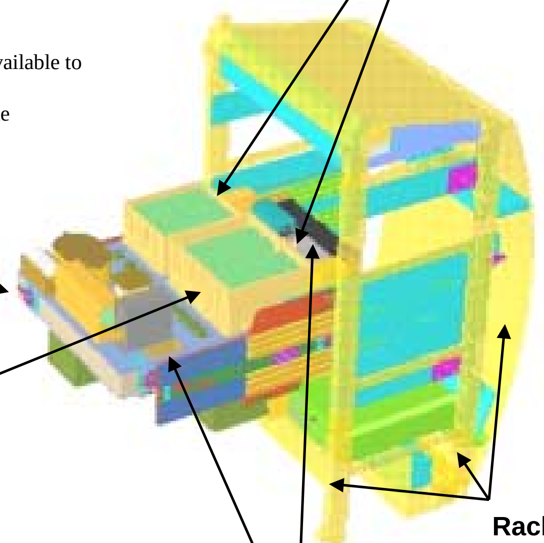


Door:

- Structural augmentation
- Thermal/Frangible laser Light containment

Optic Plate:

- Width: 86.5 cm
- Length: 112 cm
- Depth: 12.7 cm
- Wiring internal and external to plate



Electrical Power:

Electrical Power and Control Unit (EPCU)

- 4 PU Drawer
- Cold Plate
- Power Regulated to 28 Vdc
- 48 Switched, 28 Vdc Channels
- Each Channel limited to 4 A

Avionics:

- ISS command and data interface
- Control experiment/acquire data
- 16 I/O control channels, 32 analog input channels, 8 analog output channels
- 16 bit analog to digital conversion
- Up to 100 KHz sampling rate, 1 KHz std
- Control/timing, light detection interfaces, motion and temperature controllers, photomultiplier/APD interface, signal conditioning, automated position and tracking and motor drivers.

Rack:

- Baseline Dash 4
- Standard ARIS
- FCF Slide Package

Illumination & Laser Packages:

- White Light via fiber Weave
- LED Array
- Laser Diodes (10 mW each)
- Nd: YAG (60 mW)
- HeNe (1.0 mW)

Software:

- Embedded Internet Technology
- Platform Independent
- Allows for PI interaction at home site

4.2.3 FCF Fully Deployed - Shared Accommodations Rack

The Shared Accommodations Rack (SAR) is the third and final FCF element launched to the Space Station. It is currently scheduled to fly to Station in a Centrifuge Accommodations Module (CAM) on Utilization Flight #7. The SAR will then join the CIR and FIR to make an integrated facility, accommodating 10 – 20 combustion and fluids experiments per year.

The addition of the SAR is paramount to FCF meeting its system design goals. Prior to deployment of the SAR, the Combustion Integrated Rack (CIR) and the Fluids Integrated Rack (FIR) will function as single 'integrated' racks on Station, allowing for early combustion and fluid physics research opportunities. However, the scientific productivity of these individual racks will be limited by the physical envelope, mass and capability that can be accommodated within the racks, as well as the limited resources that will be available from Station during this period.

The SAR supports *both* fluid physics and combustion research in the ISS in the following primary ways:

1. The SAR contains shared on-orbit equipment; volume and capability that may be utilized by *both* research disciplines. Shared avionics in the SAR such as image acquisition and processing computers, mass data storage, removable storage media and post processing computers will support science operations in all three facility racks. Avionics launched with the SAR will replace and/or augment avionics that were temporarily placed in the CIR and the FIR and will incorporate the latest state-of-the-art command and data handling technology.
2. The SAR is designed with accommodations and interface such that PI experiments can be run directly within it and utilize its extensive command and data handling capabilities. It is envisioned that the SAR will accommodate small experiment packages, commercial and international payloads and a subset of the fluid physics basis-type experiments to maximize PI throughput during the FCFs operational life.
3. The SAR will provide dedicated volume for needs such as thermal control, stirring and preparation of experiment samples, as well as stowage of experiment equipment, supplies and spares. In addition, on-orbit chemical/physical analysis capabilities, calibration apparatus and other equipment which will maximize the effectiveness of the on-orbit FCF system may be located in the SAR.

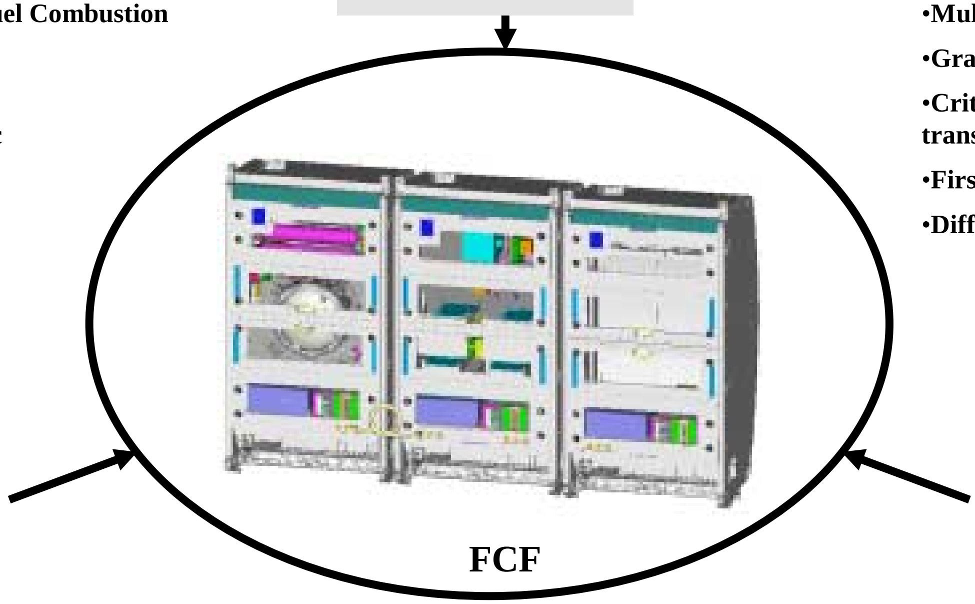
The following figure illustrates the broad science capable with the three rack FCF.

FCF/SAR Mission: Fluids Physics and Combustion Research on ISS

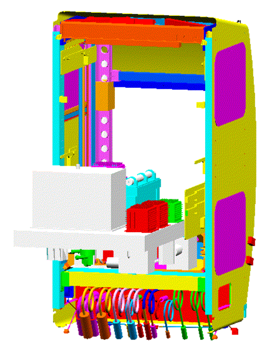
<u>**Combustion Science**</u>

- **Laminar Flames**
- **Reaction Kinetics**
- **Droplet and Spray Combustion**
- **Flame Spread**
- **Fire and Fire Suppressants**
- **Condensed Phase Organic Fuel Combustion (including coal combustion)**
- **Turbulent Combustion**
- **Soot and Polycyclic Aromatic Hydrocarbons (PAH)**
- **Materials Synthesis**
- **Detonations & Explosions**

SAR



CIR



FIR

<u>**Fluid Physics**</u>

- **Capillarity (isothermal)**
- **Thermocapillarity**
- **Colloids**
- **Fluid Rheology (including polymers)**
- **Electrohydrodynamics**
- **Multiphase Flow**
- **Granular Media**
- **Critical Fluids (second order phase transformations)**
- **First Order Phase Transformations**
- **Diffusive Phenomena**

Fluids PI Experiments
Combustion PI Experiments
Commercial & International Payloads

4.3 Ground Segment

4.3.1 Ground Segment Elements

The Ground Segment, located at the NASA/GRC provides the following: 1.) those functions necessary to perform on-orbit mission operations that the GRC Telescience Support Center (TSC) does not provide, specifically a flight-like user interface, and 2) the capability to mirror and trouble shoot on-orbit operations through the use of a unit equivalent to the Flight Segment. The Ground Segment is comprised of an Embedded Web Technology (EWT) Server and a Ground Integration Unit (GIU).

4.3.1.1 Embedded Web Technology Server

The FCF Flight Segment utilizes EWT software to provide an interface to the on-orbit crew. To provide commonality between what the on-orbit crew and ground personnel see and do, a ground based EWT server will provide an interface the same as the on-board crew interface. This interface will be available to the FCF operations team, the PI, and PI support teams. This server interfaces with the TSC hosted EHS & TReK systems.

4.3.1.2 Ground Integration Unit

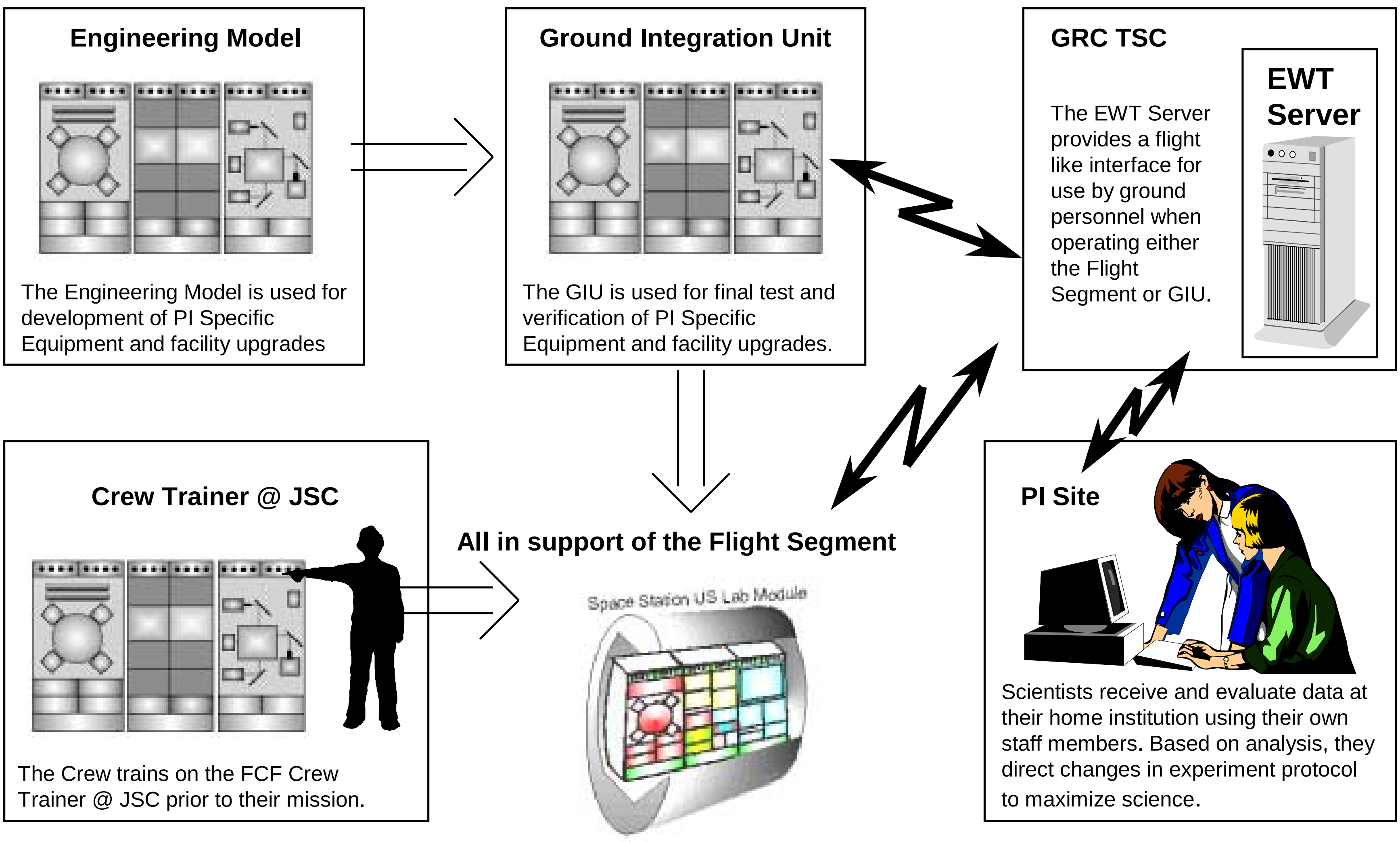
The GIU duplicates the Flight Segment. There are a few physical differences, such as aluminum rather than composite racks, due to cost and limitations of working in a 1-G environment, but every effort is made to keep the form, fit and function identical to the Flight Segment. The GIU permits science and operations to be performed on the ground while mirroring (with 1-G limitations) the science and operations that are being performed on orbit. Scientists will be able to capture the data from the 1-G testing to compare with that obtained in microgravity.

The GIU will also be used to support troubleshooting of problems encountered with the Flight Segment. The GIU is either locally controlled, or can be accessed via the TSC so that PIs at remote sites and the FCF operations team can access it in the same way that they access the Flight Segment.

The GIU also performs a supporting function for the FCF System. It allows PI specific equipment and Flight Segment upgrades to be validated on the ground prior to their launch. Testing in a flight equivalent unit will verify that the interfaces are correct and should prevent on-orbit interface incompatibilities.

The following figure illustrates the Ground Segment and mission support equipment that the FCF requires.

Ground Segment and Mission Support Equipment



4.3.2 Ground Segment Interfaces

The Ground Segment EWT Server physically interfaces with the TSC and the Enhanced HOSC System (EHS) system that it hosts. The FCF operations team and PI remote sites access the EWT server via TSC provided Internet like communication networks. The GIU interfaces with support systems and GRC infrastructure in order for it to operate and communicate with the TSC.

4.3.2.1 Telescience Support Center

The FCF operations team will be based at the TSC, NASA/GRC, building 333. During the mission, the operations team will work closely with the PI and his/her associates. The team will operate FCF at the direction of the PI and handle all hardware issues and interface issues with other NASA Centers and ISS; thus, the PI will be free to concentrate on maximizing the scientific return of the experiment. The TSC interfaces with the POIC which in turn interfaces with the ISS and FCF on-orbit.

The TSC provides the following functions:

- Receives and processes Flight Segment data via ISS systems and the MSFC Payload Operations Integration Center (POIC), and routes it to the EWT server, FCF ground operations team and/or to the PI remote Telescience Resource Kit (TReK).
- Receives data/commands from the EWT server, FCF operations team and/or the PI remote TReKs and relays them to the Flight Segment via the POIC and ISS systems.

The vast bulk of FCF data will be sent to the earth in near real time (versus recording on permanent media for later return from ISS). All Flight Segment data received by TSC will be stored a minimum of 90 days. This allows PIs or any remote sites easily to access stored data at a later date. Prior to the end of the 90 days, the data will also be archived. Archived data will be readily accessible for a period of ten years.

Data returned to the Earth on permanent media will also be made available for a period of time prior to archiving.

4.3.2.2 PI Remote Sites

PIs will be able to operate their experiment from their own site (typically at their university). They will be able to receive data and initiate commands just as though they were located at GRC, MSFC, or any other NASA center. The PIs will utilize a TReK provided by the TSC. TReK is a PC-based, data and command system that will allow PIs to monitor and control experiments located on-board the ISS from any PI remote site in the world. The PIs are also able to access the EWT server from their sites via TSC systems. PI remote sites will easily pay for themselves by reduced travel costs and increased science (because the PIs will be surrounded by their own experienced science staffs). The PI sites should not require staffing by FCF personnel due to the simplicity and fail safe nature of system.

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4.3.3 FCF Engineering Model

In addition to the Ground Segment, the FCF project is providing a piece of support equipment that is vital to the preparation of PI specific hardware and Flight Segment upgrades. That is the FCF Engineering Model (EM). The EM will be used in the early development of PI specific hardware and Flight Segment upgrades as a test bed. It will allow compatibility and other tests to be run prior to the build of the flight equipment. While the GIU's configuration and operations will need to be strictly controlled, the EM will more readily accommodate changes and will not be as strictly controlled, allowing for exclusive science support use.

Initial compatibility and performance problems will be solved using the EM. This reduces the risk of the GIU from being tied up doing troubleshooting. This is extremely important in order to maintain the scientific throughput desired for FCF.

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4.4 FCF Mission Scenario

A typical mission or increment is based on a 90 day operating cycle divided into approximately 3 periods offering a quality microgravity environment. After all equipment is removed from the resupply vehicle and all docking activities are concluded, experiment operations can begin.

A typical increment that includes FCF planned operations would begin with all equipment stowed on board the ISS or in the return vehicle for return to earth. For a typical combustion experiment this would encompass such things as experiment mounting structure changeout, or fuel container replenishment along with filter changout. Any samples designated for return are expected to be part of the experiment equipment. Fluid experiment samples may also be part of the returned experiment equipment with the exception of small samples changed out during glovebox operations.

After the replenishment activities, the FCF may remain inactive until the scheduled operation period. At this time the FCF will be powered on and checked out and any necessary commands will be uplinked to the FCF. For a typical combustion experiment, such as the Droplet Combustion experiment, the facility will be on for up to 8 hours during which the crew will perform any required setup. The desired test points will be executed and data will be downlinked to the PI in real or near real time. In the event downlink resources cannot support this, the FCF will be able to store data internally until the required downlink bandwidth is available. After the test points are run and data downlinked, the PI will be given time to analyze the data while the FCF is shut down. During dormant periods, the ground operations team will coordinate with MSFC to verify the next FCF scheduled run time.

After the combustion experiment has been executed, and while the data is being analyzed, the FCF can be powered up and a Fluid science experiment can be conducted. The crew will again do any required setup (expected to be minimal) and the FCF will be allowed to run for the duration of the experiment. For this type of fluid experiment the run time is estimated at up to 72 hours (continuous) with minimal data downlink. At the conclusion of the fluid experiment the FCF will again be shut down and allowed to remain inactive until the next operating period.

This process will be repeated for each microgravity period scheduled for the increment. During the time between increments the ground operations team will do any required maintenance to their systems and prepare for the next increment.

These preparations will include coordinating stowage locations with the ISS crew and logistics manager, updating procedures and planning products, as well as coordinating with the PIs any commands for uplink or special instruction that are not part of the on orbit procedures.

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Chapter 5 – FCF Common Hardware Design

5 FCF COMMON HARDWARE DESIGN

5.1 Government-furnished Equipment (GFE) Items

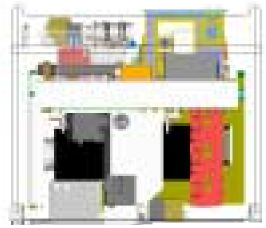
5.1.1 International Space Station Rack (–4 ISPR)

The International Space Station Rack (ISPR) provides a framework for mounting subsystem packages and transmits inertial loads generated by these entities during ground, flight, and on-orbit acceleration events to the carrier interface. These graphite-epoxy and aluminum structures are Standard Payload Outfitting Equipment (SPOE) and incorporate the following features:

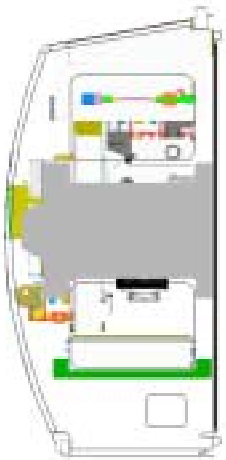
- **Mechanical attachments** for SPOE and FCF-specific assemblies, packages, and components
- **Enclosed volume** to contain Air Thermal Control and fire suppression mediums (when the door is closed)
- **Pressure relief** to limit the differential pressure between the rack internal volume and external environment
- **Mechanical attachments** for the rack carrier (RHA, MPLM, and U.S. Lab Module) interface hardware
- **Mechanical attachments** for the rack ARIS actuator and sensor hardware
- **Access ports and panels** on the rack outer skin to provide access for service on-orbit
- **Electrical grounding and bonding attachments** to provide a common electrical ground for all Facility hardware

The ISPR and some of its features are shown in the following figure.

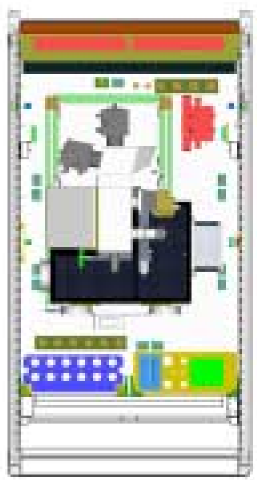
FCF Structural Subsystem Description: –4 ISPR



Top View

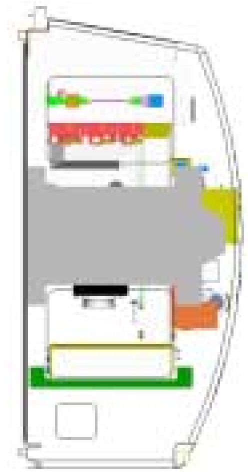


Left Side View

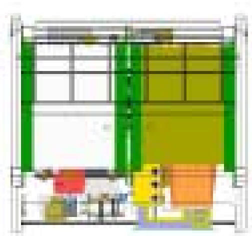


Front View

Rear View



Right Side View



Bottom View

5.1.2 Electrical Power Control Unit (EPCU)

The EPCU performs power distribution, conversion, control, management and fault protection functions associated with the operation of the FCF rack. The EPCU provides:

- 3kW of 120 VDC to 28 VDC bulk power conversion
- 2.9kW of unprocessed but protected power at 120VDC
- 6 fault protected power circuits of 120VDC
- 48 fault protected power circuits of 28 VDC
- Coordinated prioritized load shedding of all power output circuits
- Power bus transfer capability for all loads
- Isolated dynamic power sharing capability between two ISS electrical power busses.

All power output circuits are configurable by the user to allow for custom load configurations. The EPCU interfaces with the FCF Command Data Management System (CDMS) via a 1553B interface bus at the IOP. An EPCU Shut-ff Switch Assembly (ESSA) mounted on the front of the rack can be used to manually disable all 28 VDC and 120 VDC output channels.

The EPCU is located in the bottom of the rack to minimize cable lengths between the EPCU and the RUP. The EPCU is an integrated power system building block and consists of an integrated, water cooled power package that requires 4 PU of rack height and contains all the 120 Vdc to 28 Vdc power conversion and all of the EPCU Flexible remote power controller modules (FRPCMs).

The major components of the EPCU are as follows:

- A cold plate that provides the conductive cooling of all EPCU hardware.
- Six 120 VDC/4.0 ADC current limited output channels available at two connectors, 3 channels per connect on the back panel.
- 48 – 28 VDC/4.0 ADC current limited output channels available at 12 connectors, 4 channels per connector, on the front panel.

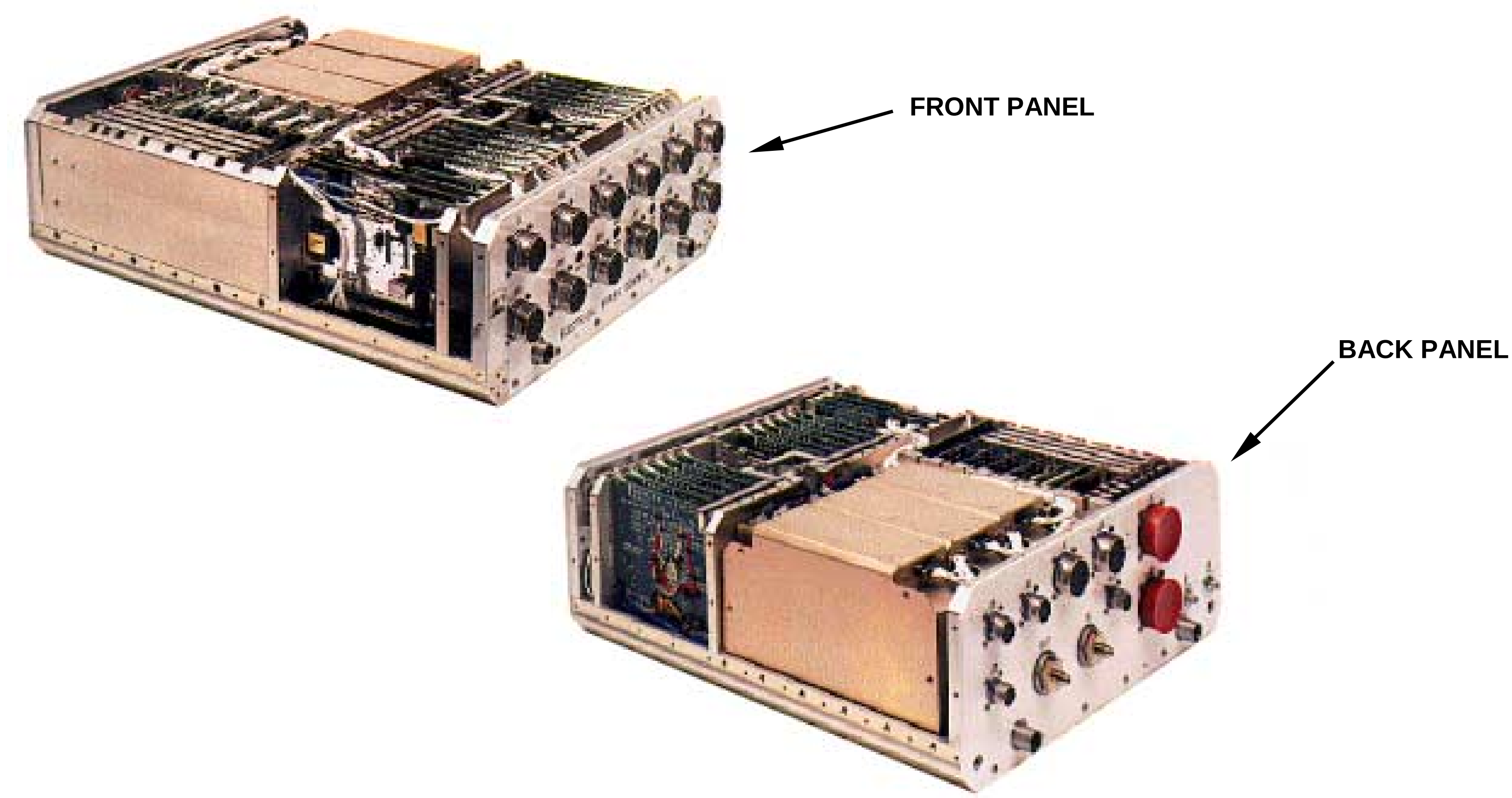
EPCU Interfaces

The EPCU provides for the interfaces rquired to operate from a nominal 120 VDC ISS Interface B power source and the interfaces to other FCF subsystems.

- Two connectors ine ach EPCU provides for the ISS Channel A (120 VDC @ 50 Amps) and Channel B (120 VDC @ 50 Amps) power input connections.
- Crew interface via the EPCU Shut-off Switch that is loacted on the front of the rack which can be used to manually remove power from all output channels. In addition, three EPCU front panel indicators are provided to notify the crew of EPCU status conditions.
- 1553B Command/Data interface to the IOP.
- A Rack Maintenance Switch Assembly (RMSA) that is located on the front of the rack contains a switch and a fire/smoke detector LED indicator. The RMSA switch sends a logic signal to the ISS MDM to control rack power at the ISS secondary power distribution assembly (SPDA) corresponding to the rack where that RMSA is located. Turning the RMSA switch "OFF" causes rack power to be turned off at both the rack EPCU and ISS SPDA remote power controller (RPC) simultaneously.

An overall description of the EPCU is shown in the following figure.

FCF Electrical Power Control Unit (EPCU) Description



EPCU Interfaces

The EPCU provides for the interfaces required to operate from a nominal 120 VDC ISS Interface B power source and the interfaces to other FCF subsystems.

- **Two connectors** in each EPCU provides for the ISS Channel A (120 VDC @ 50 Amps) and Channel B (120 VDC @ 50 Amps) power input connections.

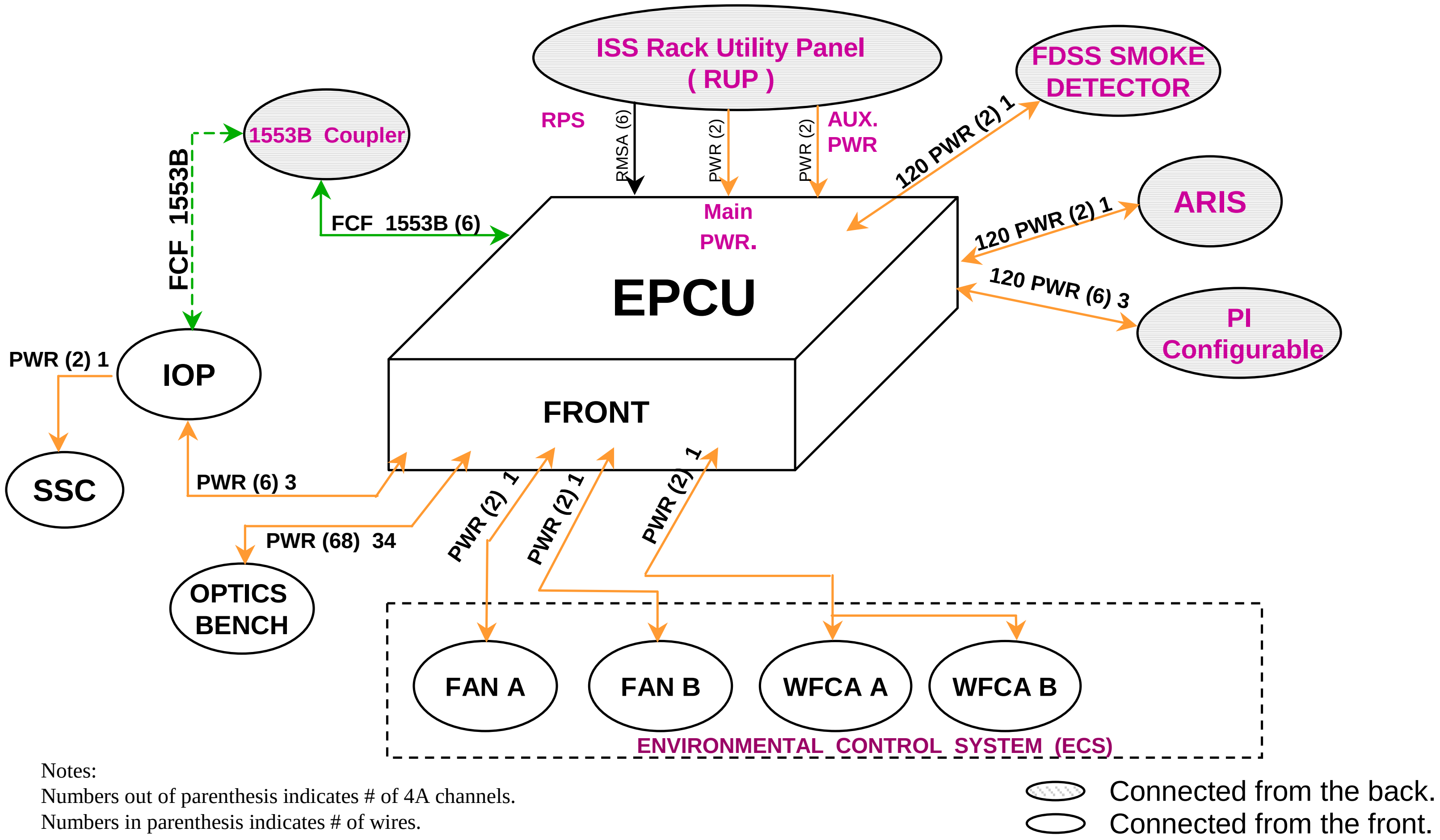
- **Crew interface** via the EPCU Shut-off Switch that is located on the front of the rack which can be used to manually remove power from all output channels. In addition, three EPCU front panel indicators are provided to notify the crew of EPCU status conditions.

- **1553B Command/Data interface** to the IOP.

- A **Rack Maintenance Switch Assembly** (**RMSA**) that is located on the front of the rack contains a switch and a fire/smoke detector LED indicator. The RMSA switch sends a logic signal to the ISS MDM to control rack power at the ISS secondary power distribution assembly (SPDA) corresponding to the rack where that RMSA is located. Turning the RMSA switch “OFF” causes rack power to be turned off at both the rack EPCU and ISS SPDA remote power controller (RPC) simultaneously.

The following figure illustrates the EPCU external interfaces.

Electrical Power Conversion Unit (EPCU) External Interfaces



Notes:
Numbers out of parenthesis indicates # of 4A channels.
Numbers in parenthesis indicates # of wires.

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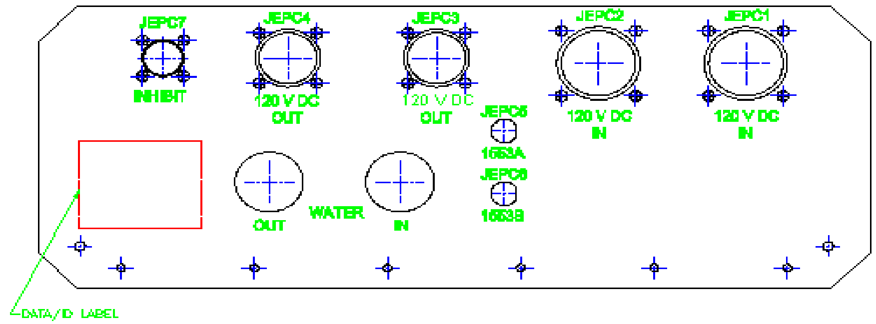
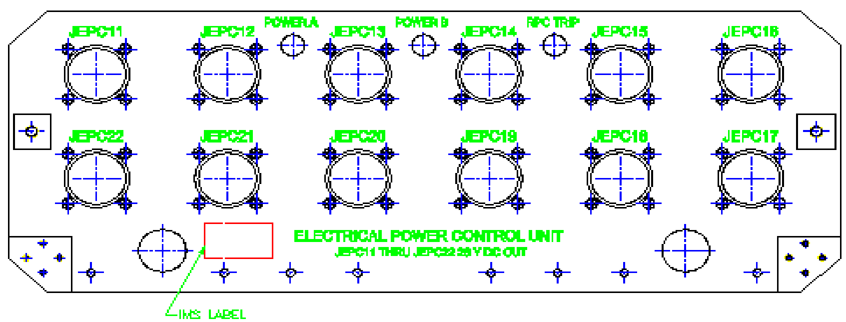
The following figure illustrates the EPCU front and back panel layouts.

EPCU Front and Back Panel Layout



(REAR OF UNIT)



(FRONT OF UNIT)

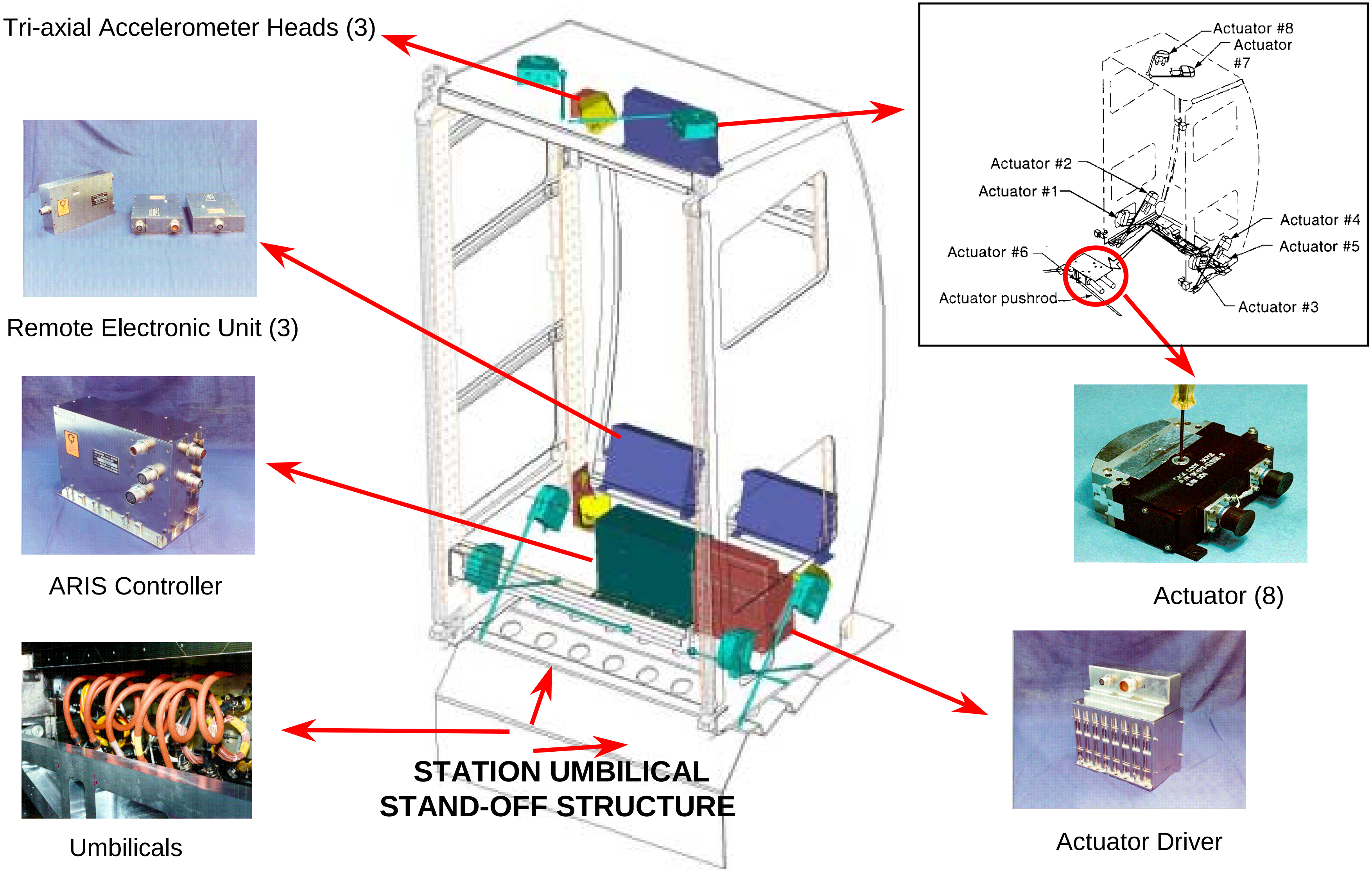
JEPC1-JEPC2: size 25L shell, 2 #4 & 1 #8 for 120VDC Input Power
JEPC3-JEPC4: size 21 shell, 16 #16 pins for 120VDC Output Power
JEPC5-JEPC6: Twinax for 1553B Interface
JEPC7: size 13 shell, 22 #22 pins, for 1553B Addressing and EPCU Shut-off Switch
JEPC11-JEPC22: size 21 shell, 16 #16 pins for 28VDC Output Power, user/facility load interface
POWER A, POWER B, RPC TRIP: LED indicators

5.1.3 Active Rack Isolation Subsystem (ARIS)

FCF experiments will be sensitive to motion and vibration. In order to not disturb these experiments, researchers have developed a system which isolates these experiments from disrupting vibrations which could reduce the likelihood of a successful experiment. The Active Rack Isolation Subsystem (ARIS) is designed to isolate certain classes of science experiments from major mechanical disturbances that might occur on the ISS, essentially acting as a shock absorber. The ARIS isolates the research payload from motion disturbances through a sophisticated electronic sensing and control system as well as umbilical cables and actuators, allowing the rack to float within a 12.7 mm (½ in.) clearance in all directions in the space station.

The elements that comprise the Active Rack Isolation System and their locations within the rack are shown in the following figure.

Major Active Rack Isolation Subsystem (ARIS) Components



5.1.3.1 ARIS Description

The ARIS provides rack-level attenuation of on-orbit low-frequency/large-amplitude mechanical vibrations transmitted from the U.S. Lab Module to the three facility racks when science operations are conducted. The subsystem incorporates the following components:

- **Accelerometers -** Three tri-axial accelerometer packages, with associated signal conditioning electronics, are mounted in standard locations in each rack. The accelerometers measure vibratory disturbances and return data to the ARIS control unit which then issues commands to eight actuators to move the entire rack on three axes, 6 degrees of freedom (DOF) to counteract the disturbances.

- **Controller -** The Controller Assembly contains the power supply, controller circuit board and digital-to-analog converter (DAC) circuit board During active isolation, the Controller Assembly is fed acceleration and position information read from the Remote Electronic Units. The Controller feeds these inputs into a control algorithm and then commands counteracting accelerations to the Actuator(s) through the Actuator Driver Assembly. The ARIS Controller Assembly is mounted on the cold plate.

- **Actuator Driver** - The ARIS Actuator Driver Assembly is mounted on the cold plate and its purpose is to drive the actuators themselves. The Actuators consist of eight independent, but identical, modules and a connecting wire harness. Each Actuator receives a differential analog command signal, a differential discrete inhibit signal and 28 VDC from the Controller Assembly.

  The controller/actuator driver water-cooled unit requires facility electrical power and data communication resources.

- **Actuators -** Eight (8) electro-mechanical actuators are located in each rack at interfaces between the Facility ISPRs and the U.S. Lab Module structure. Each Actuator contains a motor, a pushrod and a position sensor. The motor is driven by the Actuator Driver. One end of the pushrod is attached to the motor and the other end is attached to the US Lab through the isolation plate or the standoff. Commands to the motor accelerate the pushrods, which are the mechanisms that “float” the rack.

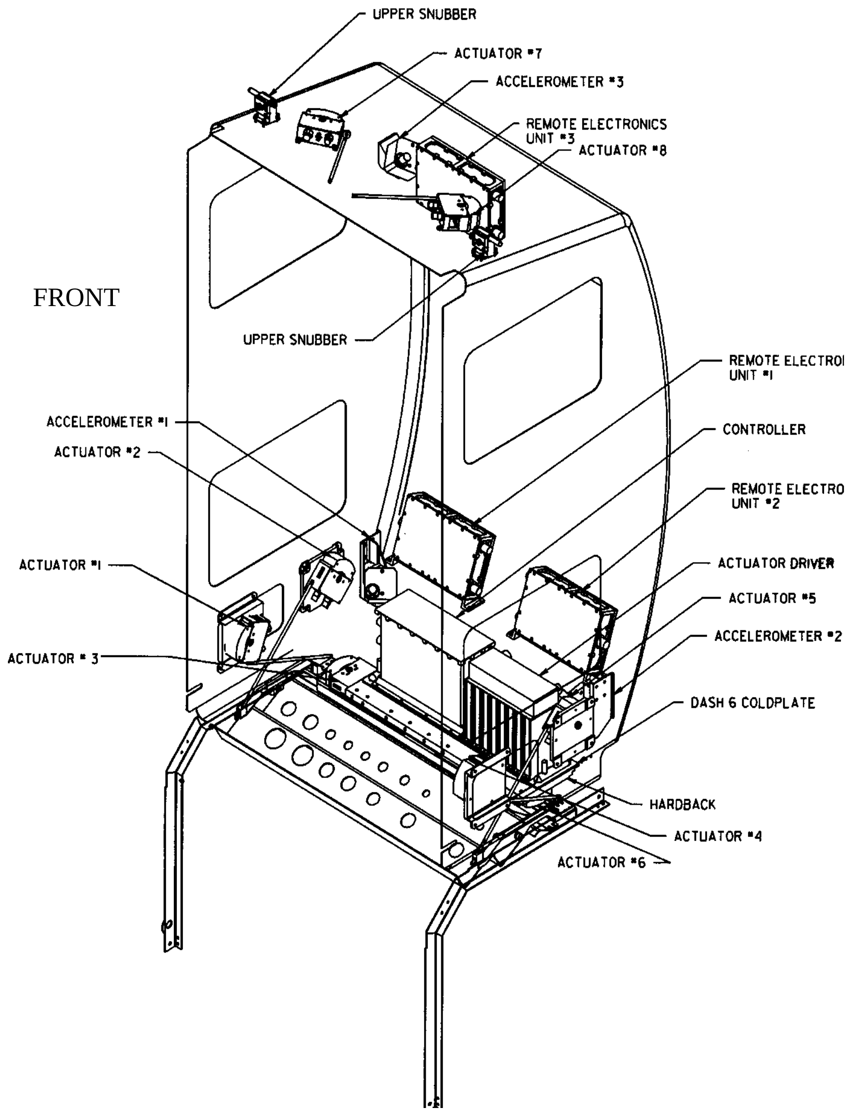
- **Remote Electronic Unit (REU)** - Three ARIS Remote Electronics Unit provide the signal-conditioning interface between the accelerometers, position sensors and the Controller. The REU converts the analog “acceleration” and “position” signals from the accelerometer and actuators, respectively, to a digital format and then transmits this data to the Controller over the REU serial bus.

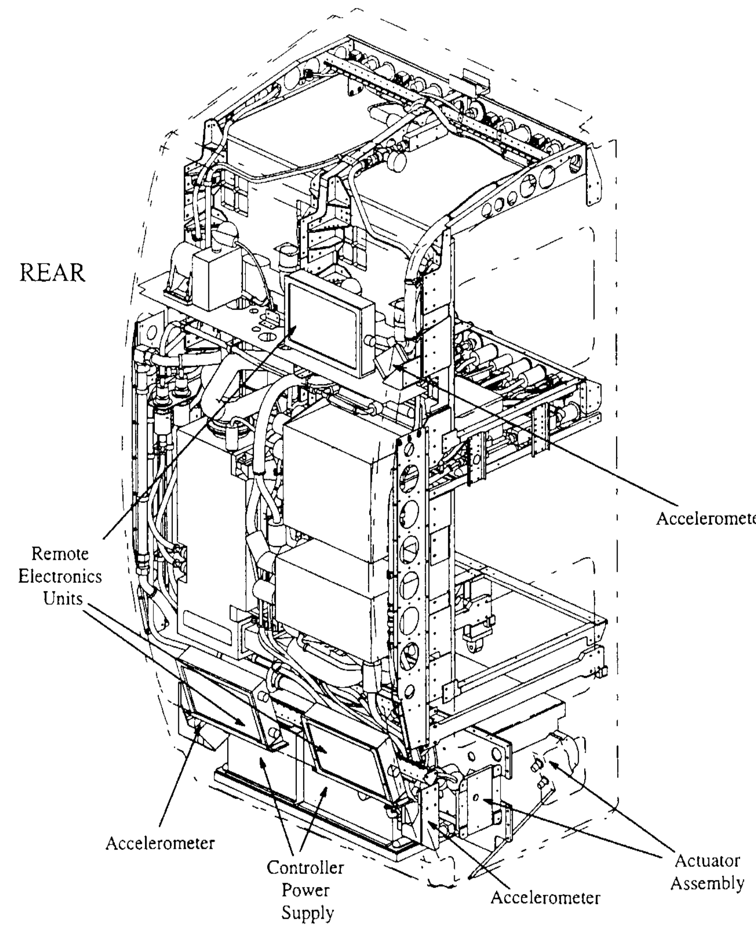
- **ARIS Umbilical Assembly -** The ARIS Umbilical Assembly provides a low bias force and spring rate connection between the U.S. Lab Module structure and the payload rack structure for utility pass-through.

  The umbilicals that run between the ISS User Interface Panel (UIP) and the Combustion and Fluids Racks have been specially designed by Boeing, the developer of the basic ARIS hardware, and are provided as part of the ARIS kit.

The elements that comprise the Active Rack Isolation System and their locations within the rack are shown in the following figure.

ARIS Rack Major Components (Front and Rear Views)





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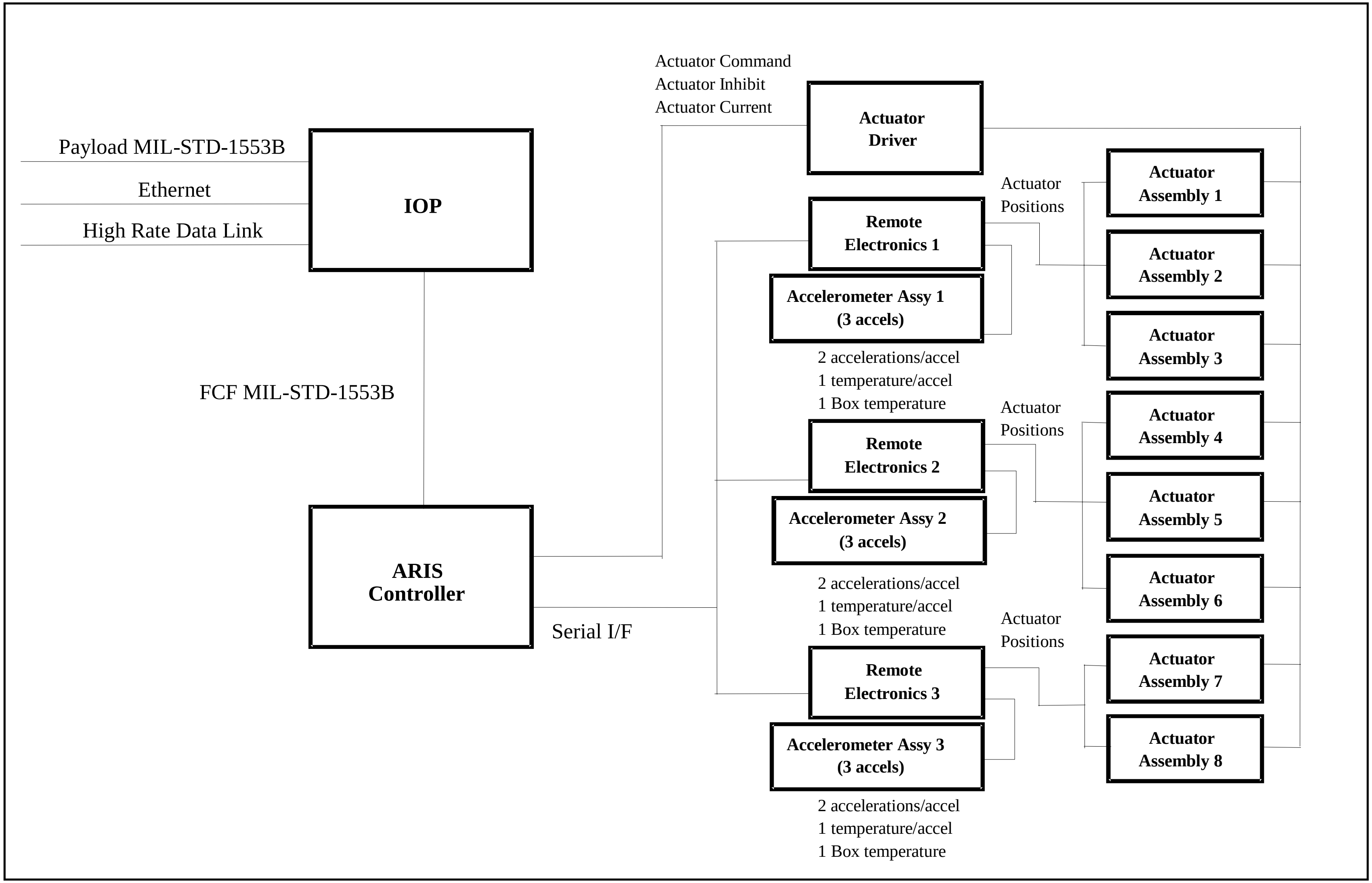
ARIS Subsystem Command/Data Interface Summary



5.1.3.2 Function and Performance

ARIS provides rack-level attenuation of on-orbit low-frequency/large-amplitude mechanical vibrations transmitted from the U.S. Lab Module to each facility rack when science operations are conducted. The principal performance metric that the payloads shall meet on-orbit is the vibration envelope shown in the following figure.

ARIS provides the unique ability to "float" an entire ISPR and isolate it from external vibration sources. ARIS is not responsible for on-board (payload-induced) disturbances caused by the rack components or by PI hardware. A combination of passive and active isolation systems may be needed to mitigate payload-induced disturbances. PI payload should be developed with to intent to minimize on-board disturbances.

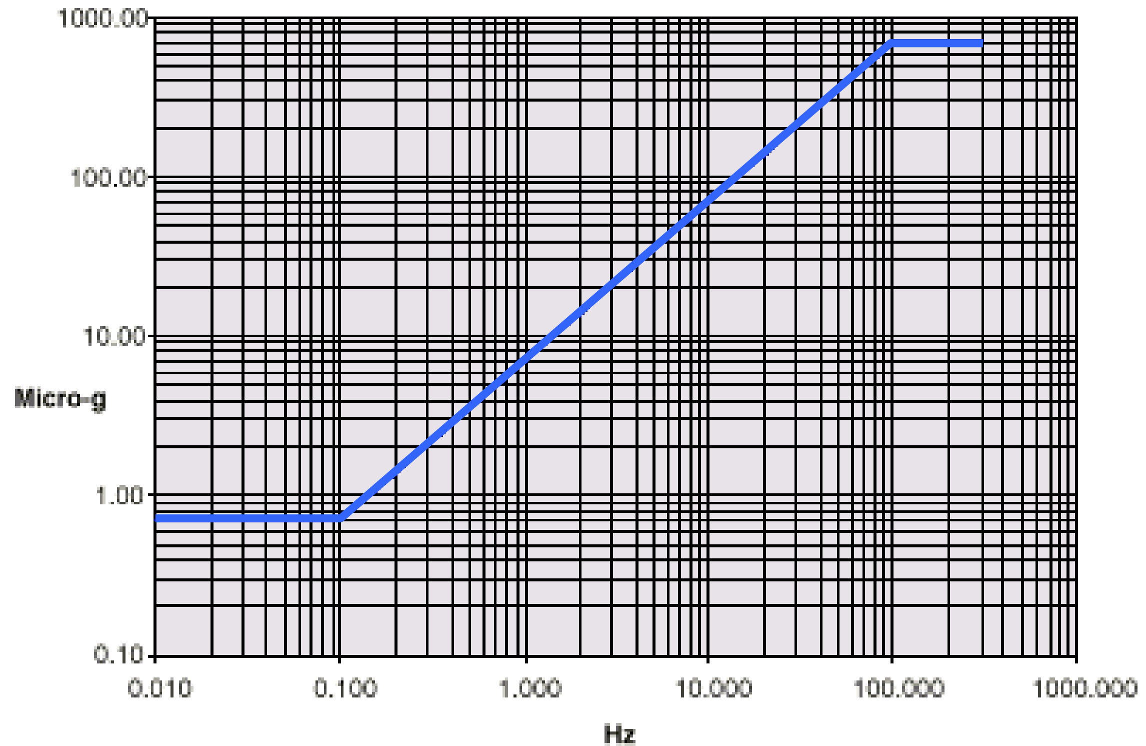
Requirements and Constraints

Requirements and constraints for the ARIS can be found in the following documents.

- **Interface Compatibility -** Active Rack Isolation Subsystem Interface Description Document (D683-61576-1 draft 7).
- **On-orbit Total ISPR Mass Limitation -** Upper mass limit for optimal ARIS performance is 804.2 Kg maximum for the total ISPR.

The attenuation provided by ARIS is shown in the following figure.

Anticipated ARIS Acceleration Attenuation



5.1.4 Space Acceleration Measurement System (SAMS)

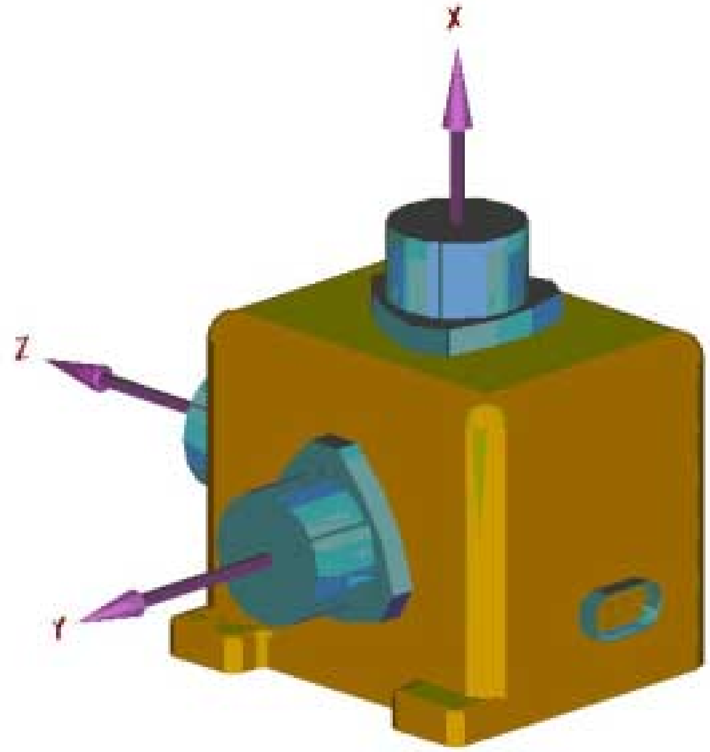
Multiple frequency selection, combined with signal level detection within the Space Acceleration Measurement System-Free Flyer (SAMS-FF) Triazial Sensor Head (TSH), expands measurement capabilities to handle a whole range of needs that formerly required multiple measurement devices. A SAMS sensor head will be used in each of the FCF racks. Additional information on SAMS-FF can be found in *SAMS Triaxial Sensor Head Interface Document* (SAMS-FF DOC-10).

Specifications of SAMS-FF:

- Allied Signal QA 3000 sensors
- Sensor output signal conditioning and filtering
- Adjustable frequency bandwidth, 0-200 Hz (under software control);can be changed during operation
- 24-bit Delta-Sigma analog-to-digital conversion for low noise and largedynamic range
- Oversampling rate at 3.8 to 1
- Full-scale range:
    - Up to ~78 milli-g (for operation, at gain of 16)
    - Up to 1.25 g (for ground calibration, at gain of 1)
- Sensor temperature measured on each individual axis
- RMS-to-DC measurements --- abbreviated sensor data
- RMS measurement at 600 Hz bandwidth and 0.1g full-scale with minimum crest factor of 5
- Digital signal output(RS-422): low noise, small cables (DB-9 connector)
- Can be used stand alone with a standard RS-422 interface and ±15V power supply
- Only 1.6 W power consumption (±15VDC)
- Compact, light enclosure: 2.9” x 2.9” x 2.8”

The following figure shows a concept of the SAMS FF TSH.

SAMS-FF Triaxial Sensor Head



5.1.5 Station Support Computer (SSC)

The FCF will utilize the Station Support Computer (SSC) to provide the crew interface for commanding and data display. The SSC is an IBM Thinkpad 760XD, which provides the following interfaces to the CIR Rack:

- Ethernet (interface to CIR Ethernet only)
- RS 232/422

The SSC will be attached to the adjacent rack seat track using the multi-use bracket. In addition the SSC can be used in conjunction with PERS when it is not feasible to attach it to the rack. Connectors will be located on the rack to provide access to 28VDC power, Ethernet, and RS-232. Displays that are developed for the SSC will adhere to the display development guidelines contained in SSP 50313 and SSP 58700 annex 6.

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5.2 Common Subsystems

5.2.1 Air Thermal Control System (ATCS)

Description

The Air Thermal Control Subsystem (ATCS) removes up to 1650 Watts of waste thermal energy generated by Facility systems using the ISPR internal atmosphere as the medium for thermal energy transfer. The Space Station Moderate Temperature Loop (MTL) is used as the sink for rejecting Facility thermal loads to the Space Station Internal Thermal Control System (ITCS). MTL water is provided via the Water Thermal Control Subsystem.

ATCS hardware is located in the Air Thermal Control Unit (ATCU). The ATCU structure is located at the top of each Facility rack. The fans draw warm air from the rear of the rack and force the air through an air filter and heat exchanger, exiting cooled air. The fans create a pressure differential from the inlet to the outlet of the ATCU which drives flow. Although the ATCU hardware is identical in all of the facility racks, the flow network varies per rack.

In the CIR, cool air flows into the top of the Optics Bench, which acts as a pressurized duct. Hardware mounted to the optics bench interface with ports in the optics bench for airflow. By design this hardware restricts air consumption in such a manner that hardware receives only its allocated air supply. Each component has a fixed pressure drop at a design flow rate. A fixed pressure differential is maintained between the interior of the Optics Bench and the rack volume. The pressure differential varies as a function of fan speed, but the maximum system pressure differential is 175 Pa.

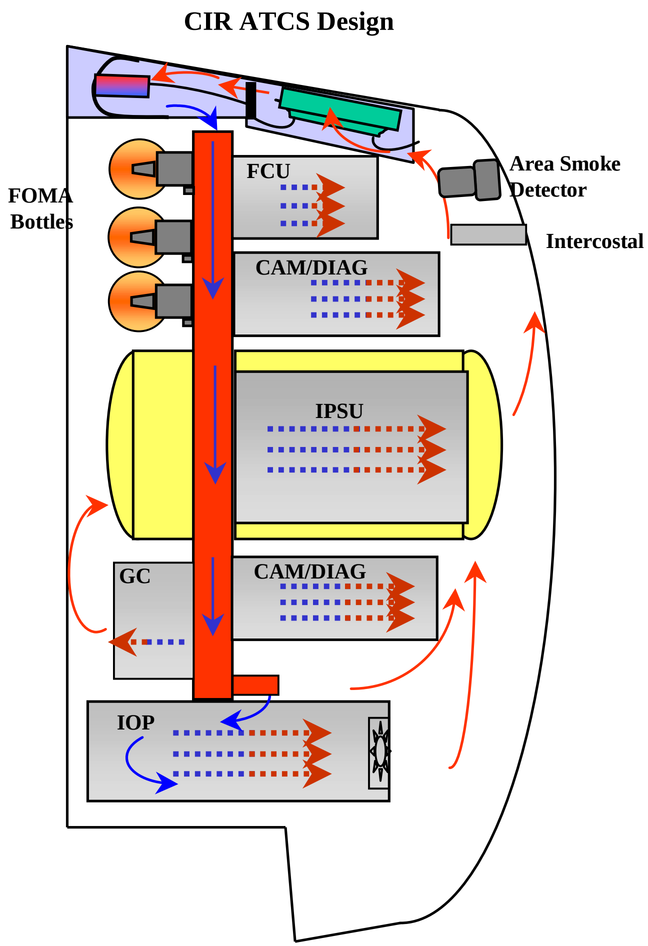
In the FCF and SAR, cool air flows into the front volume of the rack. Seals along the side of the Optics Bench force air to flow from top to bottom. A gap at the bottom of the Optics Bench allows air to flow into the rear volume of the rack. The Optics Bench is attached to the inlet of the ATCU and acts as a suction duct. Hardware mounted to the optics bench interfaces with ports in the bench for airflow. Similar to the CIR, hardware restricts its air consumption such that hardware receives only its allocated air supply. Each component has a fixed pressure drop at a design flow rate. A fixed pressure differential is maintained between the interior of the Optics Bench and the rack volume. The pressure differential varies as a function of fan speed, but the maximum system pressure differential is 175 Pa.

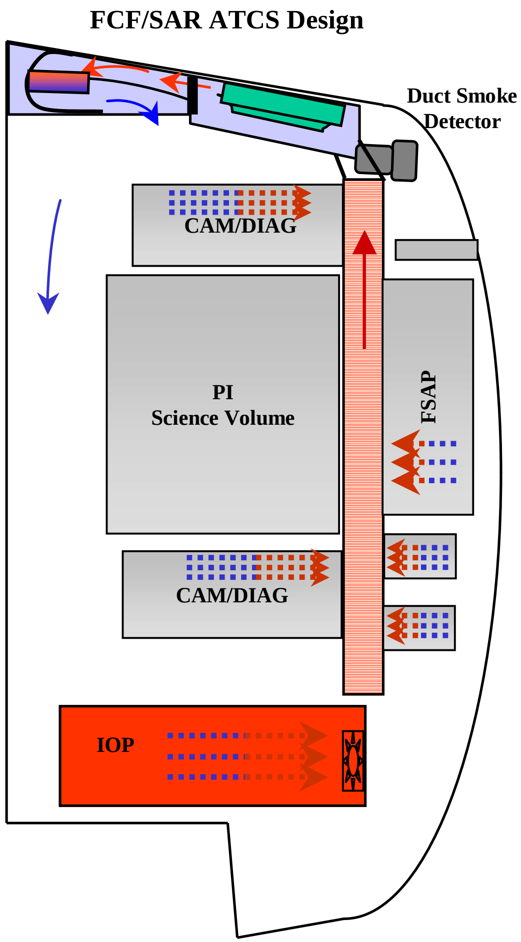
Features

- Two backward curved impellers drive the airflow
- One air to water heat exchanger rejects waste heat to the Moderate Temperature Loop.
- Heat exchanger volume: 57 mm x 101.6 mm x 990.6 mm
- Airflow paths are located on the Optics Bench at the Universal Mounting Locations (UMLs)
- Heat generating components on the Optics Bench are convection-cooled by internal airflow
- The hardware developer's job is made simpler by the generous differential pressure. The designer simply needs to direct air to the appropriate internal heat generating devices. This is accomplished via internal baffles and strategically placed air exhaust locations.
- The need for external ducting and baffling, along with the associated mass and volume, is minimized.

The following figure illustrates the Environmental Control System Concept for all three racks..

Environmental Control System Concept



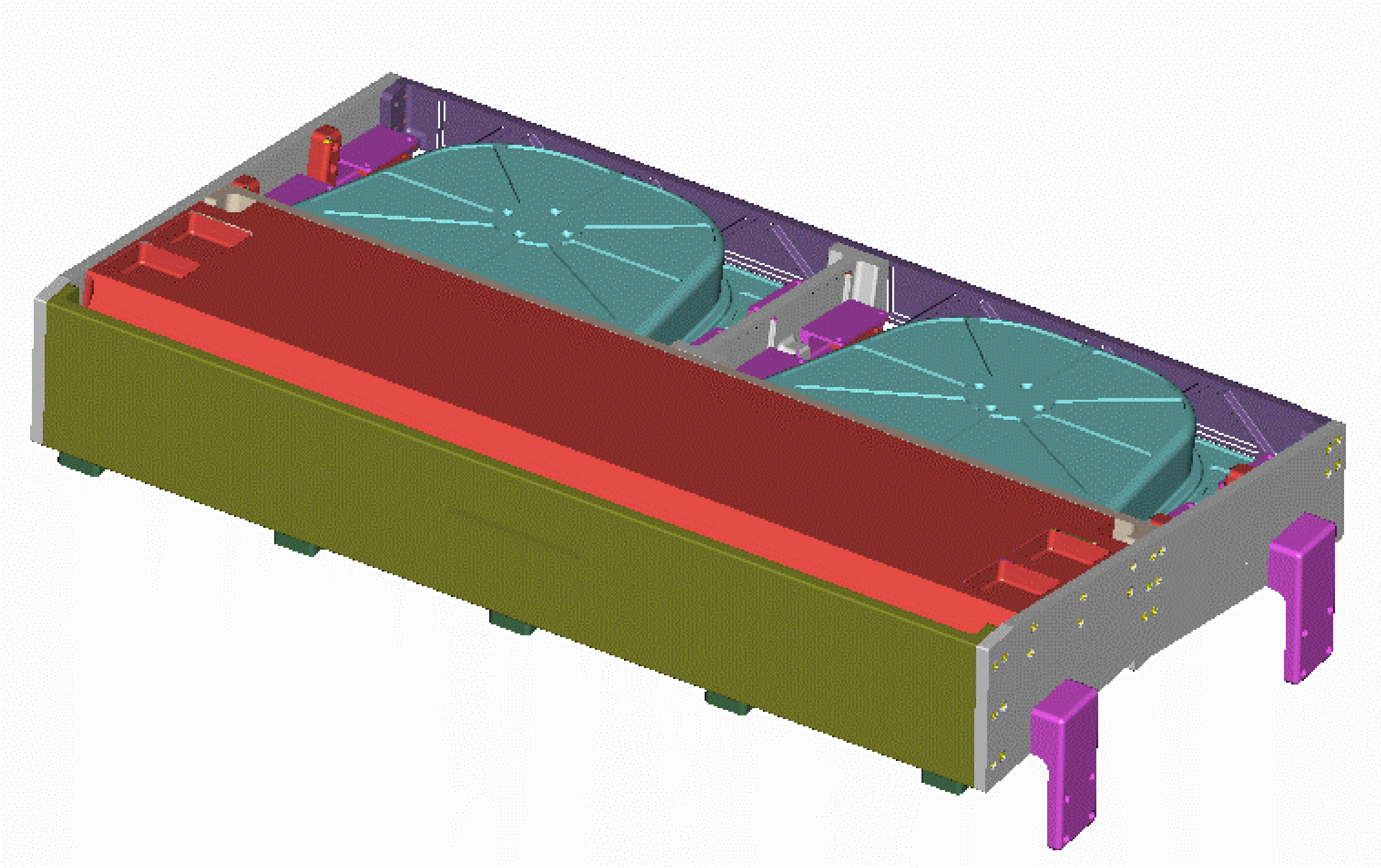


Features (cont'd)

- Hardware can be tested and verified independently of other hardware in the CIR rack.
- ATCS design eliminates last minute total system flow balancing, permits easy on-orbit reconfiguration and eliminates extensive system level ground based testing
- Components relying on natural convection cooling on the ground will receive on-orbit cooling from the general circulation of air within the rack. Air currents within the rack will be greater than those produced by natural convection.
- Air Supply Temperature: 26°C
- Air Return Temperature (maximum): 43.3°C
- Air Volumetric Flow Rate: 5.13 meters^3 /min
- Total Air Cooling Capacity: 1650 Watts
- Pressure Difference Provided: 100 Pascals

The following figure illustrates the Environmental Control Subsystem – Air Thermal Control Unit.

Environmental Control Subsystem - Air Thermal Control Unit



5.2.2 Water Thermal Control System (WTCS)

Description

The WTCS provides cooling of all Fluids and Combustion Facility (FCF) equipment by removing all the waste thermal energy generated by FCF systems and transferring it to the International Space Station (ISS) Internal Thermal Control System (ITCS) Moderate Temperature Loop (MTL).

One WTCS is located in each of the three FCF racks. The WTCS in each rack consists primarily of a distributed network of plumbing to carry supply and return flow to and from interfaces with science and nonscience packages including the Air Thermal Control Unit (ATCU) air to water heat exchanger.

Thermal energy is removed directly by contact heat transfer from the equipment to the coldplates located within FCF and indirectly through the ATCU air to water heat exchanger. The water absorbs the heat from the coldplates and the air to water heat exchangers in all three racks and delivers it to the ISS ITCS MTL.

The network of flow control valves, quick disconnects, threaded fluid fittings, flex hoses, tubing, crew accessible interface panels, and associated interconnections to coldplates and air to water heat exchangers includes both “hard-wired” and reconfigurable entities. This arrangement facilitates a variety of configurations in any of the three FCF racks and optimizes use of the limited ISS ITCS MTL water resource.

Each rack interfaces with the ISS ITCS MTL supply and return at the rack Utility Interface Panel (UIP). These services are routed to the Rack Utility Panel (RUP) using flexible umbilicals, which are part of and provided by the rack Active Rack Isolation System (ARIS). Beyond the RUP, separate networks are provided for science hardware and nonscience hardware.

The WTCS consists of:

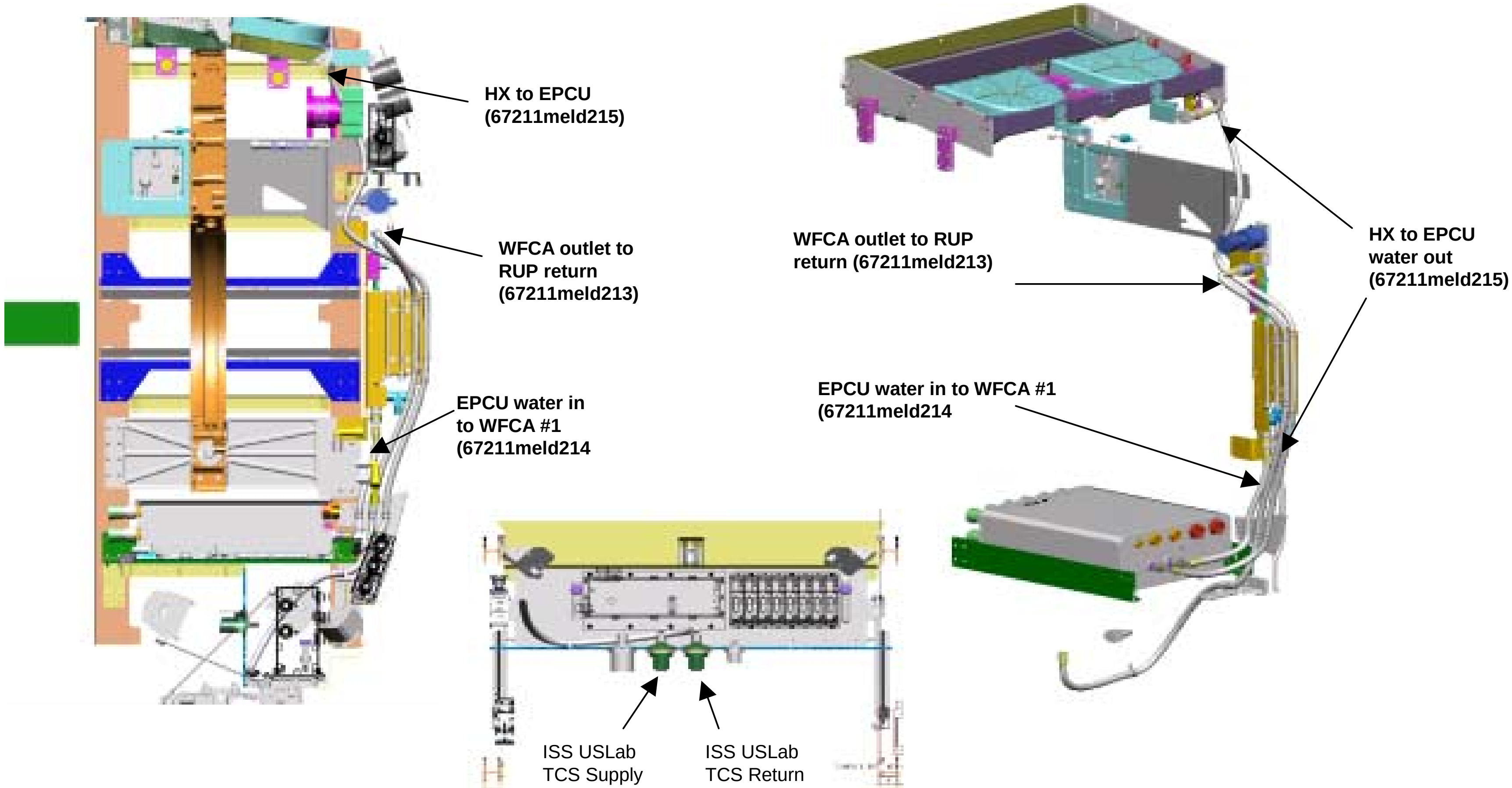
1. The Water Distribution Subsystem, which distributes water to both the Primary and Secondary Loops.
2. The Primary Loop Subsystem, which provides cooling to and includes all nonscience hardware.
3. The Secondary Loop Subsystem, which provides cooling to and includes all science hardware.
4. The Environmental Control System (ECS) Electronics Unit (EEU), which is housed in the Air Thermal Control Unit (ATCU) and has a dual role. It provides control between the FCF Input/Output Processor (IOP) and the WTCS hardware. It also provides control for the ATCU hardware.
5. The Accumulator Subsystem, which absorbs thermal control system pulsations due to temperature fluctuations. It is physically located outside the rack at the RUP and is removed on orbit.

Science hardware interfaces with the WTCS at the Water Interface Panel (WIP). The WIP is located at the middle left side of each rack. Flexible umbilicals with Quick Disconnects (QDs) interconnect the WTCS with the WIP and science hardware.

Nonscience hardware is plumbed in series in order to conserve ISS ITCS MTL water flow rate. These packages interface to the WTCS through QDs.

The following figure illustrates the Water Thermal Control Subsystem.

Environmental Control Subsystems - Water Thermal Control Subsystem



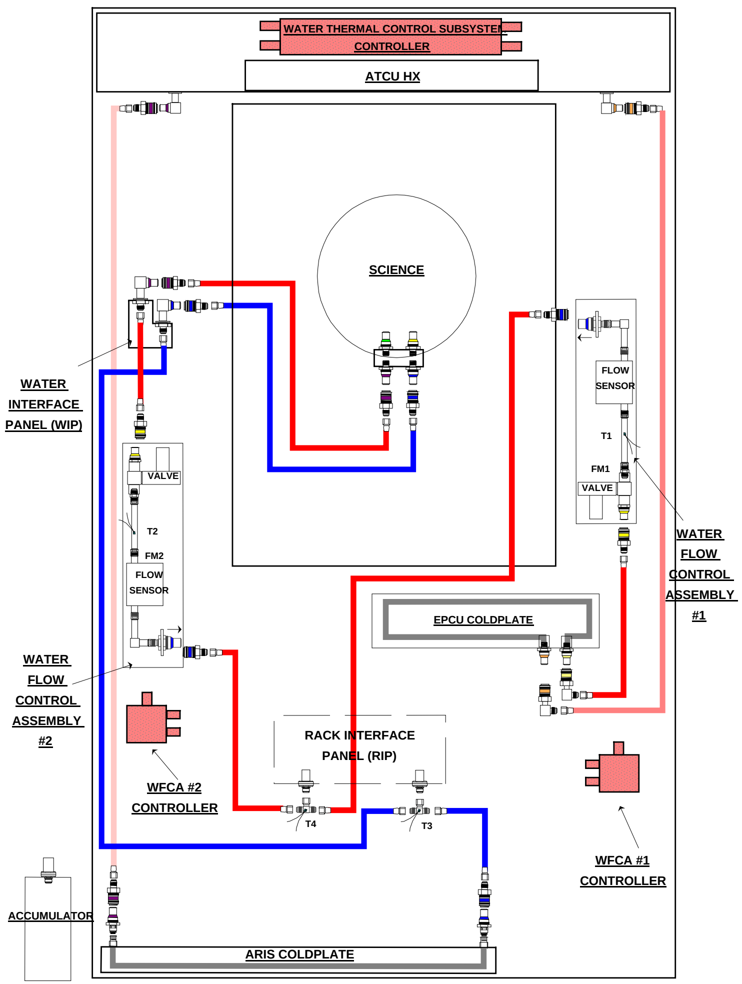
Electronically operated flow control valves on each loop (Primary and Secondary) provide flexibility to adjust flow rate to match requirements for a variety of configurations and operating modes.

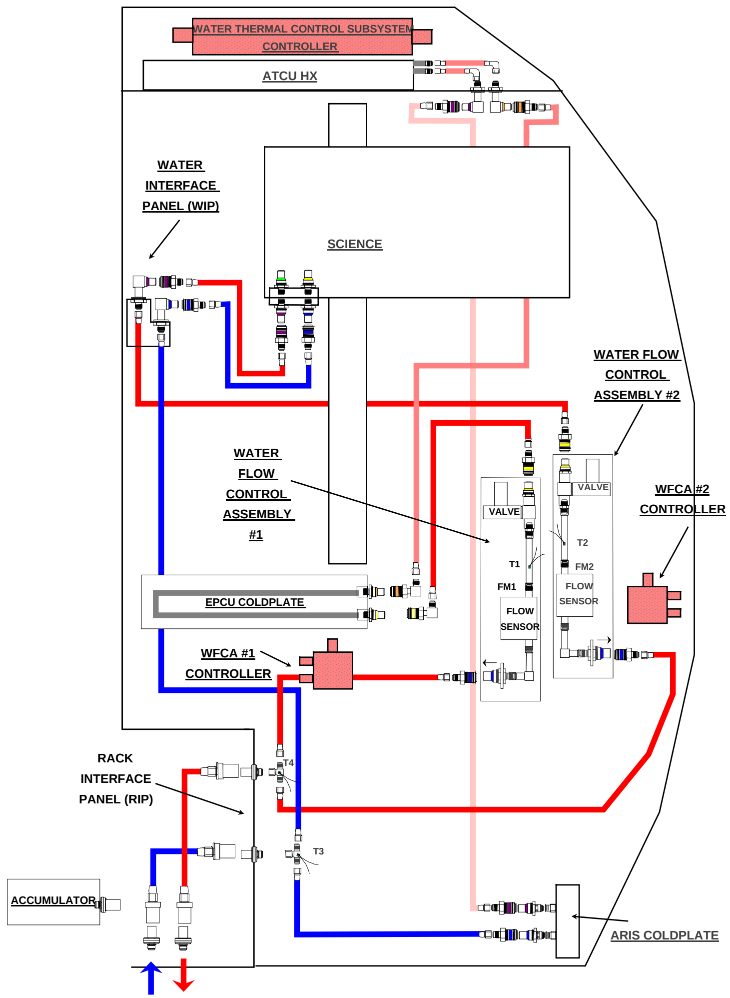
Each WTCS loop is capable of delivering up to 300 lb/h of water flow rate. The water flow rate is a function of the total power being dissipated by each rack. ISS ITCS MTL requirements dictate the amount of water available. The inlet water temperature to the racks is 65°F (18.3°C). The water flow rate will be such that the minimum water exit temperature is 100°F (37.8°C). This flow rate corresponds to about 97.5 lbm/h per 1 kW of power.

With a combined maximum of 600 lbm/h, the maximum cooling capability for each rack is just over 6 kW with a corresponding inlet-outlet temperature of 65 to 100°F (18.3 to 37.8°C).

The following figure illustrates the plumbing scheme for the Water Thermal Control Subsystem.

Water Thermal Control Subsystem Plumbing Scheme





5.2.3 Fire Detection and Suppression Subsystem (FDSS)

Description

The Fire Detection and Suppression Subsystem (FDSS) provides detection and suppression of fire events. Each rack shall be independently monitored for smoke using a Smoke Detector. The Air Thermal Control Subsystem (ATCS) provides global air circulation to assure appropriate air sampling. The ATCS shall be activated immediately at rack power-up.

Upon detection of a fire event within a rack, a crew member will don a portable breathing apparatus and will obtain a Portable Fire Extinguisher (PFE). The crew member will insert the PFE nozzle into a port provided at the top of the rack. The crew member will discharge the entire contents of the PFE into the rack. Dispersion of CO_2 will be accomplished via normal air cooling paths within the rack and by suffusing around the Optics Bench..

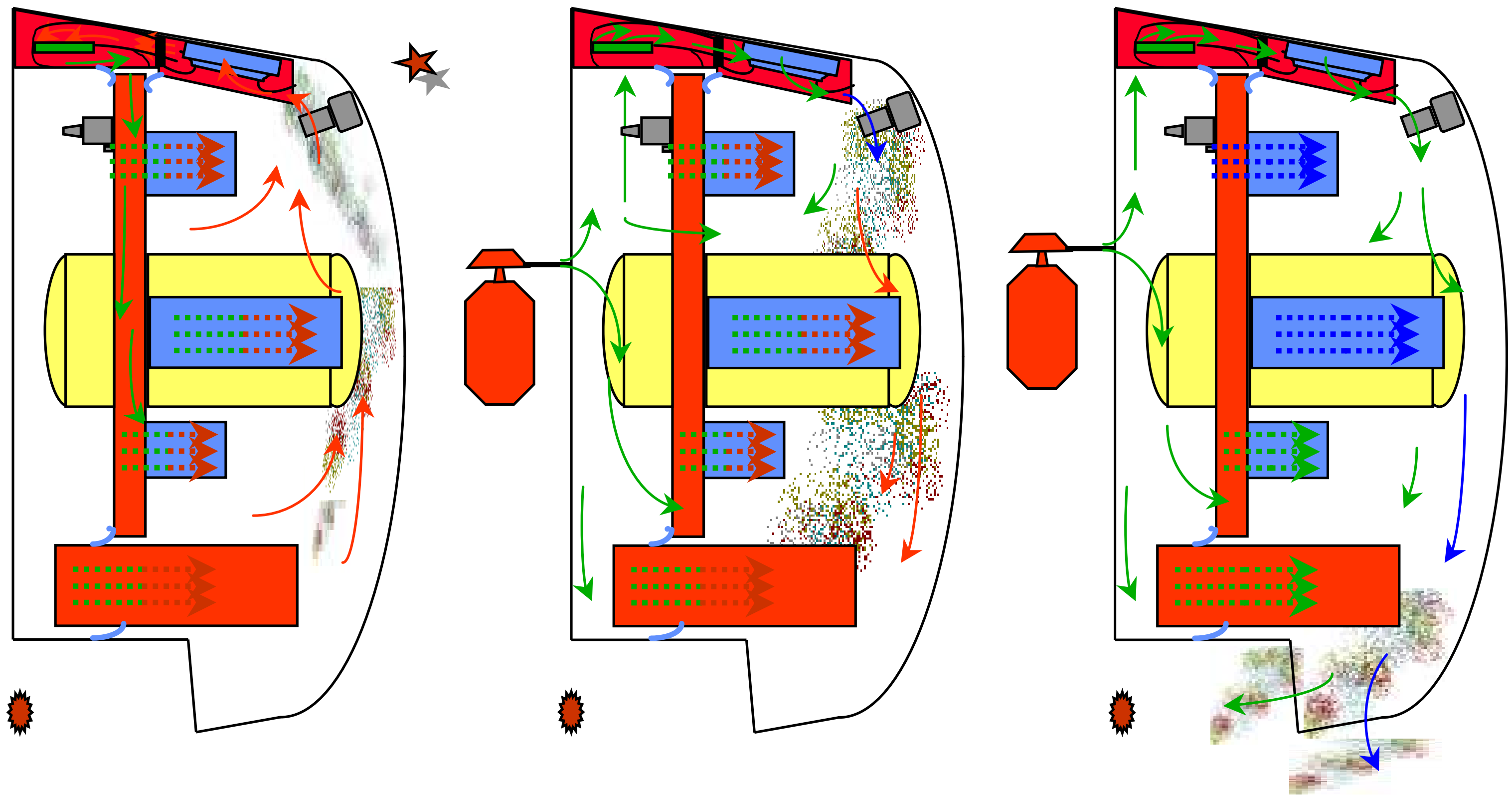
Features

The Smoke Detector is ISS-developed hardware. The CIR requires an Area Smoke Detector. The Smoke Detector uses laser light attenuation and laser light scattering to detect smoke. The primary light source for the smoke detector is a near-infrared laser diode. A photo-diode regulates the luminosity of the light output throughout the life of the laser. The Smoke Detector requires 1.5 watts of input power and weights 1.41 kg.

Individual packages within the rack provide temperature information to the Command and Data Management Subsystem (CDMS). High internal package temperatures are indicative of impending fire events.
The Injection Port provides the crew with the capability to manually release CO_2 suppressant into the rack via the portable fire extinguisher.

The following figure illustrates the ISPR Fire Detection and Suppression Subsystem.

Fire Detection and Suppression System



Step 1. Smoke Detector indicates a fire event signals ISS systems which shut off power and alerts the crew.

Step 2. Crew inserts and dispenses portable fire extinguisher (PFE) into access port in rack door.

Step 3. Fire event is extinguished.

5.2.4 Input/Output Processor (IOP)

Description

The IOP performs the command processing, control, data processing, data management, caution and warning, health and status monitoring and time synchronization for the Facility. The IOP incorporates the following features:

- 7-slot, 6U card cage hosting the main IOP processor, a 16x16 video switch, a 24 port Ethernet switch, the HRDL , and the CVIT.
- 2, 73.4 Gigabyte Ultra160 SCSI hard disks for data buffering. These drives are removable from the front of the IOP for replacement or returning data to earth.
- CANbus fiber optic converters for rack-to-rack communications.
- Analog video fiber optic transmitter and receiver.
- Sync bus generator with fiber optic transmitter/receiver.
- Power Supplies and EMI filters.

5.2.4.1 Interface Connection

The IOP provides the data and command paths to/from the Space Station, between other subsystems within and between the racks in the FCF. It includes the following:

- MIL-STD-1553B Bus interface to ISS.
- FCF MIL-STD-1553B Interface to the EPCU and ARIS. Couplers for this bus are internal to the IOP.
- 10BaseT Ethernet interfaces to ISS (Payload and Telemetry), and the SSC.
- 100BaseT Ethernet interfaces to the PI Specific Box, FOMA Control Unit (FCU), and Image Processing Packages (IPPs).
- 1000BaseF Ethernet between all FCF racks. This Gigabit Ethernet interface links the Ethernet switches in all FCF IOPs.
- HRDL interface to ISS.
- Thirteen differential analog video inputs to video switch from the Optics Bench.
- One differential analog video output from the video switch to the Optics Bench.
- Analog video output from the video switch to ISS video system and the SSC or monitor.
- Analog video fiber optic transmitter and receiver interfaced to the video switch transmits analog video between all FCF racks.
- CANbus shared by IPSUs, diagnostic packages, FOMA, and PI Specific hardware. This CANbus is converted to fiber and linked between all FCF racks.
- CANbus for the ECS.
- Sync signal generator, programmable from 1 to 1kHz in 5 Hz increments, provides a square wave clock signal to the Optics Bench UML and PI interfaces for synchronizing diagnostic packages.
- Sync signal converted to fiber optics for synchronizing hardware in other FCF racks.

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5.2.4 Input/Output Processor (IOP) (concluded)

The following table identifies the power requirements for this architecture. The connections to each subsystem within the rack will be distributed as follows:

- All connections to the IOP are made through connectors on the IOP front panel.

The connectors to be used are:

Front Panel

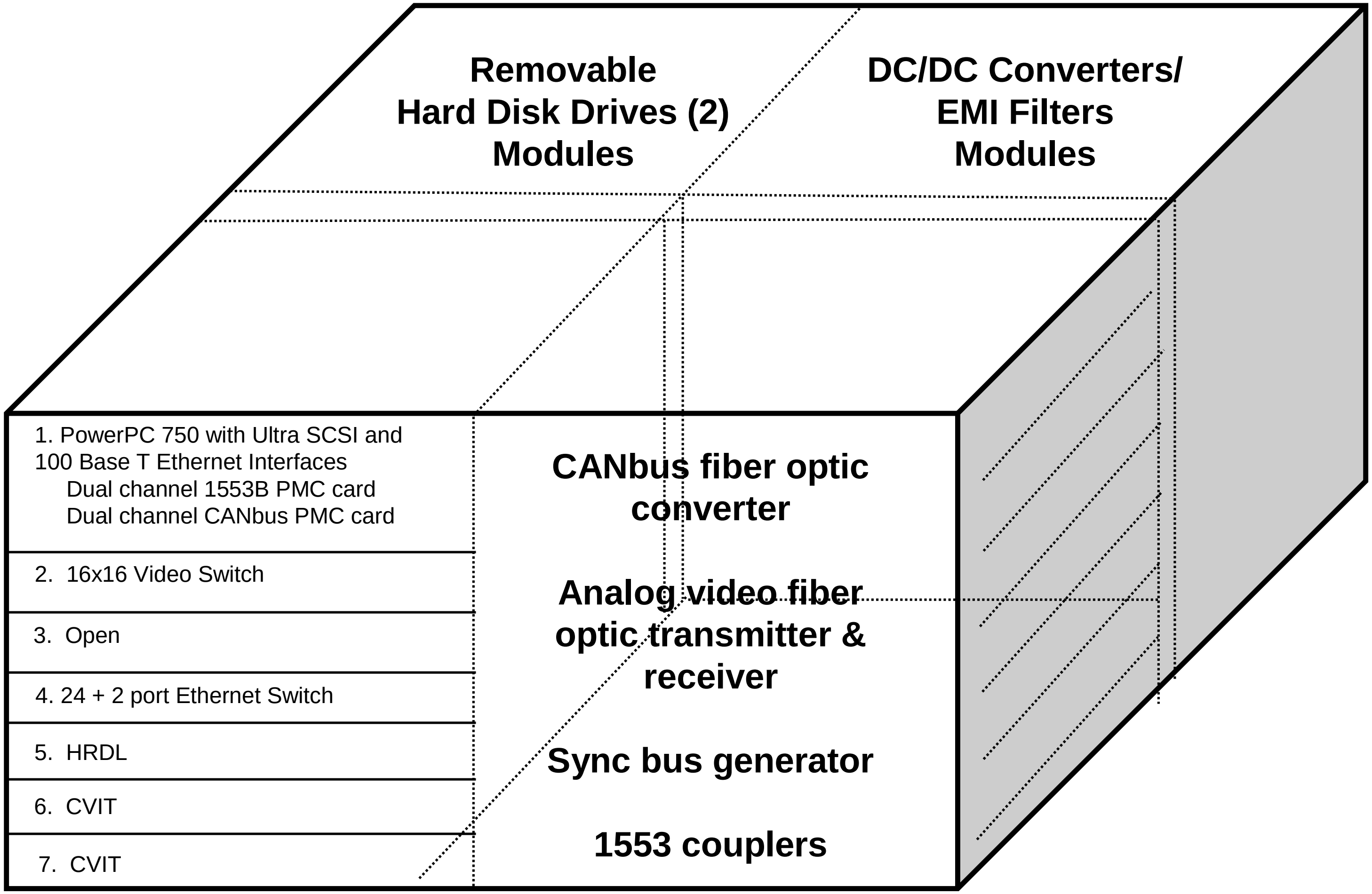
- One MIL-C-38999, 13 socket, 22 gage connector for SAMS power and RS-422 data.
- One MIL-C-38999, 100 socket, 22 gage connector for the Optics Bench CANbus, Ethernet, Sync bus, and analog video.
- One MIL-C-38999, 8 pin, 16 gage connector for power.
- One MIL-C-38999, 37 socket, 22 gage connector for ISS 1553B, ISS Ethernet, ARIS and EPCU 1553B, and ECS CANbus.
- One MIL-C-38999, 10 socket, 20 gage connector for the SSC power, SSC Ethernet, SSC analog video, external monitor analog video.
- One MIL-C-38999, 2 socket, 16 gage connector for the HRDL and CVIT fibers.
- One MTP, 12 multimode fiber optic ribbon cable adapter for rack to rack Ethernet, analog video, Optics Bench CANbus, and Sync signal.
- One MIL-C-38999, 6 socket, 22 gage connector for the rack door switch.
- One MIL-C-24308, DB-9 socket, 20 gage connector for ground test only of the IOP main processor and HRDL single board computer.

The connectors information for the front panel is as follows:

- JIOP-1: D38999/24FB35SN, 13 socket, 22 gage connector for SAMS power and RS-422 data.
- JIOP-2: D38999/24FH35SN, 100 socket, 22 gage connector for the Optics Bench CANbus, Ethernet, Sync bus, and analog video.
- JIOP-3: D38999/24FE8PN, 8 pin, 16 gage connector for power.
- JIOP-4: D38999/24FD35SN, 37 socket, 22 gage connector for ISS 1553B, ISS Ethernet, ARIS and EPCU 1553B, and ECS CANbus.
- JIOP-5: D38999/24FC98SN, 10 socket, 20 gage connector for the SSC power, SSC Ethernet, SSC analog video, external monitor analog video.
- JIOP-6: D38999/24FB2SN, 2 socket, 16 gage connector for the HRDL and CVIT fibers.
- JIOP-7: MTP-ADPT, 12 multimode fiber optic ribbon cable adapter for rack to rack Ethernet, analog video, Optics Bench CANbus, and Sync signal.
- JIOP-8: D38999/24FA35SN, 6 socket, 22 gage connector for the rack door switch.
- JIOP-9: M24308/2-281, 20 gage connector for ground test only of the IOP main processor and HRDL single board computer.

The following figure illustrates the CIR IOP package contents.

IOP Package Contents



* There is only one CVIT, but it require 2 slots.

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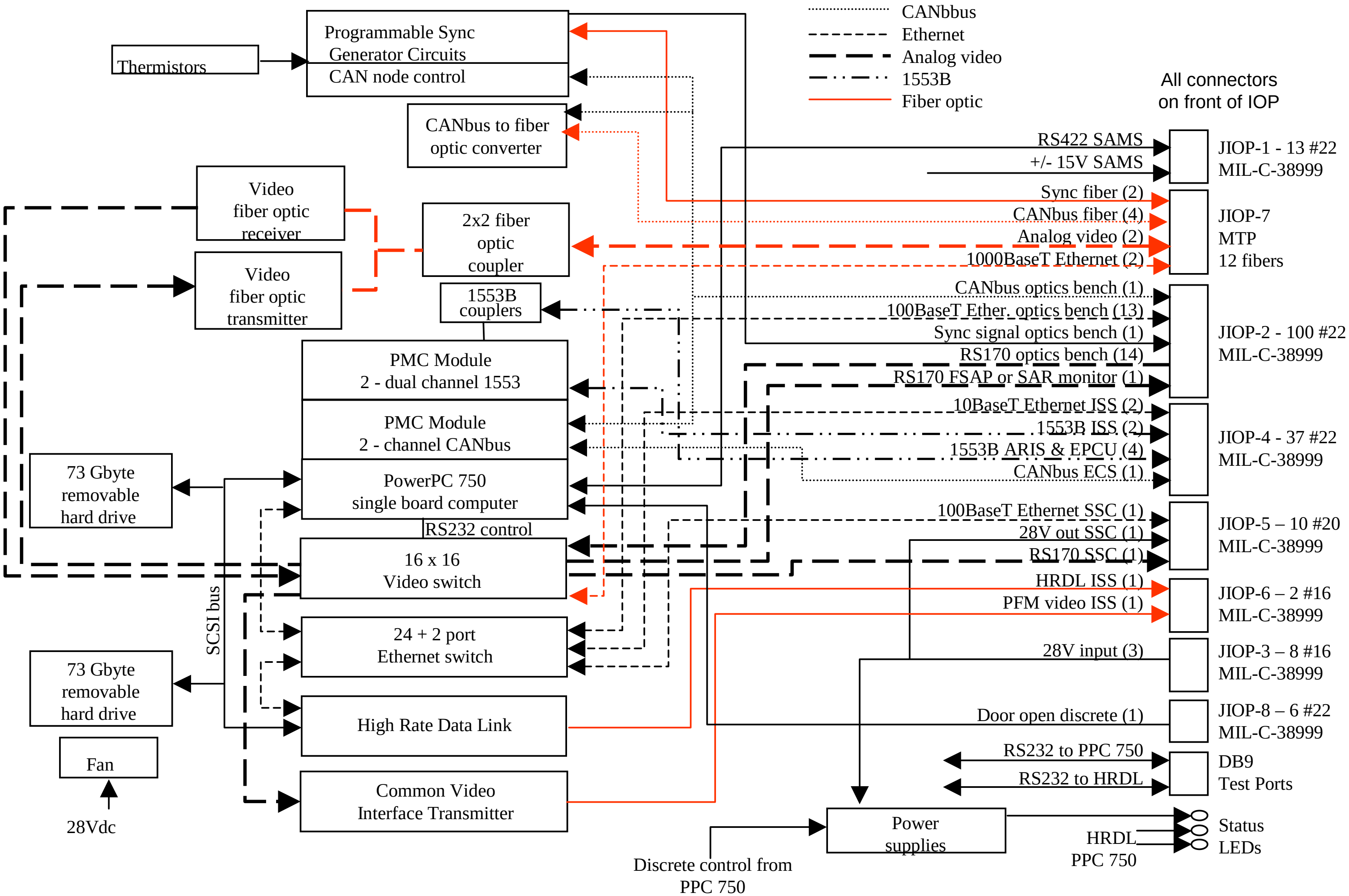
The following figure illustrates the CIR IOP block diagram.

Input/Output Package (IOP) Block Diagram



5.2.4.2 IOP Operations

The IOP functions as the Bus Master for the Facility Internal 1553B Bus and accepts commands/data as a Remote Terminal on the ISS C&DH 1553B Bus. The IOP accepts the ISS timing signal and distributes that timing signal to the EPCU via 1553B and provides a time synchronization server to all other processors via Ethernet.

All data to be down-linked to the ISS must come through the IOP via Ethernet, 1553B or CANbus interfaces. The IOP receives science, and ancillary data via the Ethernet and CANbus. The data is then formatted and down-linked via the1553B, HRDL or MRDL interfaces.

Video data to be displayed on a video monitor or the Laptop is sent via the 16x16 video switch located in the IOP. Video data to be sent to the ISS monitor must come through the IOP CVIT board to be formatted into the PFM format prior to sending it to the ISS video system.

Digital image data from the Image Processing packages will be buffered on one of two 73.4 Gbyte hard drives located in the IOP for downlink through the HRDL Interface.

Safety related parameters will be provided to the ISS via the 1553B interface as required.

The Station Support Computer laptop (SSC) will provide the crew interface for data monitoring, commanding, and control. Commands and files from the ground will be received at the ISS Payload 1553B interface or from one of the ISS LAN interfaces.

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5.2.5 Image Processing Storage Unit (IPSU)

FCF will provide extensive image acquisition, processing, and management, as is typically required for fluids physics and combustion experiments. The Image Processing Storage Unit (IPSU) will provide support for a wide range of digital cameras common to the FIR and CIR.

An Image Processing Storage Unit (IPSU) will provide an interface for acquiring data from digital cameras in real-time. Each IPSU is designed to support image acquisition for digital cameras in the imaging packages. Each IPSU will interface with its respective camera for digital data acquisition and with thee science avionics for command and control. The IPSU will store video data in a digital format. The data acquired will be compressed (if required) to reduce memory and transfer bandwidth and processed to support closed loop control scenarios such as focusing, zoom, and tracking. The dimensions of an IPSU are 290 mm x 224 mm x 224 mm (11.4 in. x 8.8 in. x 8.8 in.).

Each IPSU consists of a 6-slot compact PCI backplane that consists of the following items:

- A **single board computer** with an Ethernet interface for data downloads
- An **Ultra2 SCSI disk controller card**
- A **CANbus controller** for data communications, and for health and status
- A **Frame-grabber interface board**
- A **Digital Signal Processing** (**DSP**) **card** for image processing
- **Mass storage** includes two 18.2GB hard disk drives. A portion is allocated to the operating system.

Boundaries

The IPSU will interface with the 28 VDC circuits that are available from the EPCU.

Constraints

The following constraints apply to the IPSU:

- **IPSU configuration** is limited to the initial set of facility-provided imagers described later in this document. **Upgrades** and potential **IPSU change-out** (or partial change-out) are possible.

- The **bandwidth** is known to decrease as the data moves from the image processor towards permanent storage or downlink.

Functional Requirements

The imaging will be sufficient to provide video data for a variety of purposes including the following items:

- Experiment setup and optical alignment
- Measurement of test object sizes
- Measurement of test object movement
- Measurement of test object color
- Recognition of critical events or change in experiment status
- Efficient storage and retrieval of video image data

The image processing system consists of an image processor capable of acquiring raw video data at 40 Mb/sec. Limited preprocessing of that data can also be accomplished at this rate. The system can store a maximum of TBD MB of raw video data in its main memory. Assuming that some optimization can be done in real time, this number is expected to improve. It will be a design goal of the team to optimize this capability.

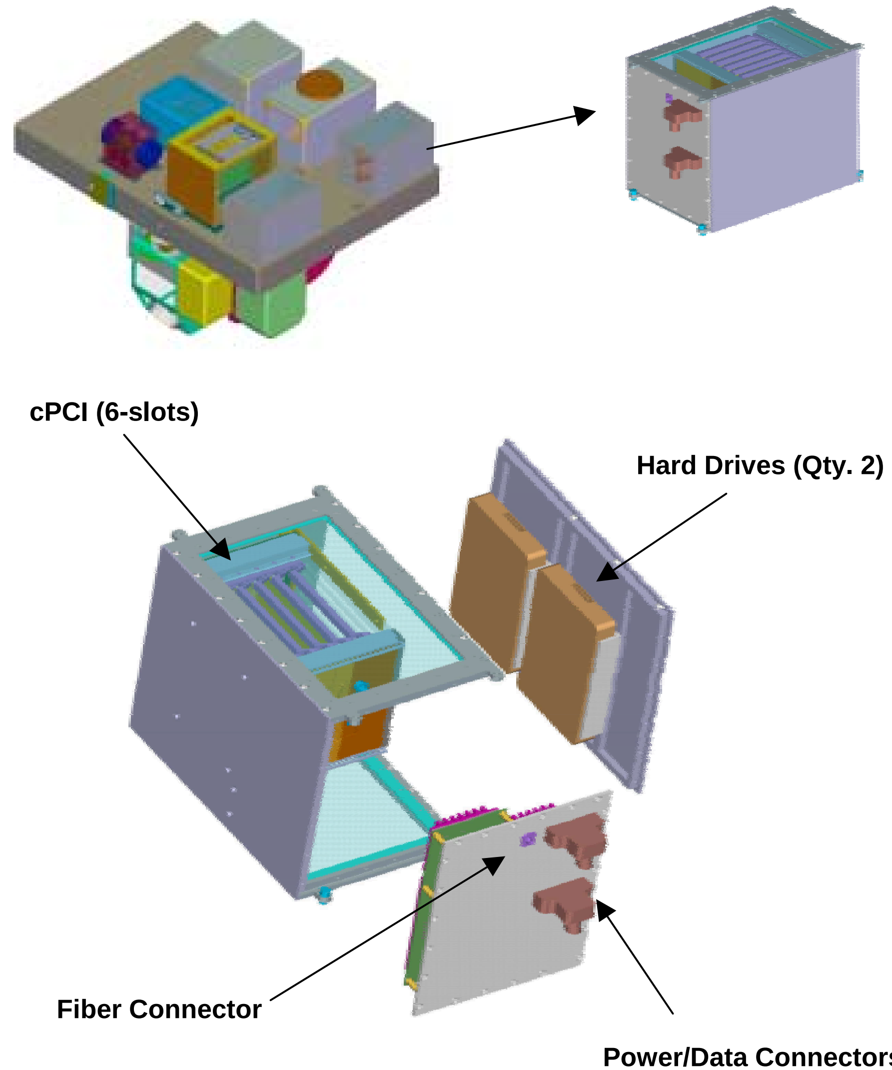
The following figures show the configuration of the IPSUs in the FIR/SAR and CIR as well as the interfaces of the IPSU.

FCF Image Processing and Storage Unit (IPSU)-FCF/SAR Configuration

Hybrid Backplane

Compact PCI Backplane (3U Form Factor)

1. PEP CP302 Pentium III Single Board Computer
   - PEP CP360 Ultra2 SCSI Disk Controller
2. BittWare Quad Processor DSP
   - General Standards Frame-grabber Board
3. Greenspring cPCI IP Carrier Board
   - Greenspring CAN IP Module
4. Custom-designed Serial Data Link



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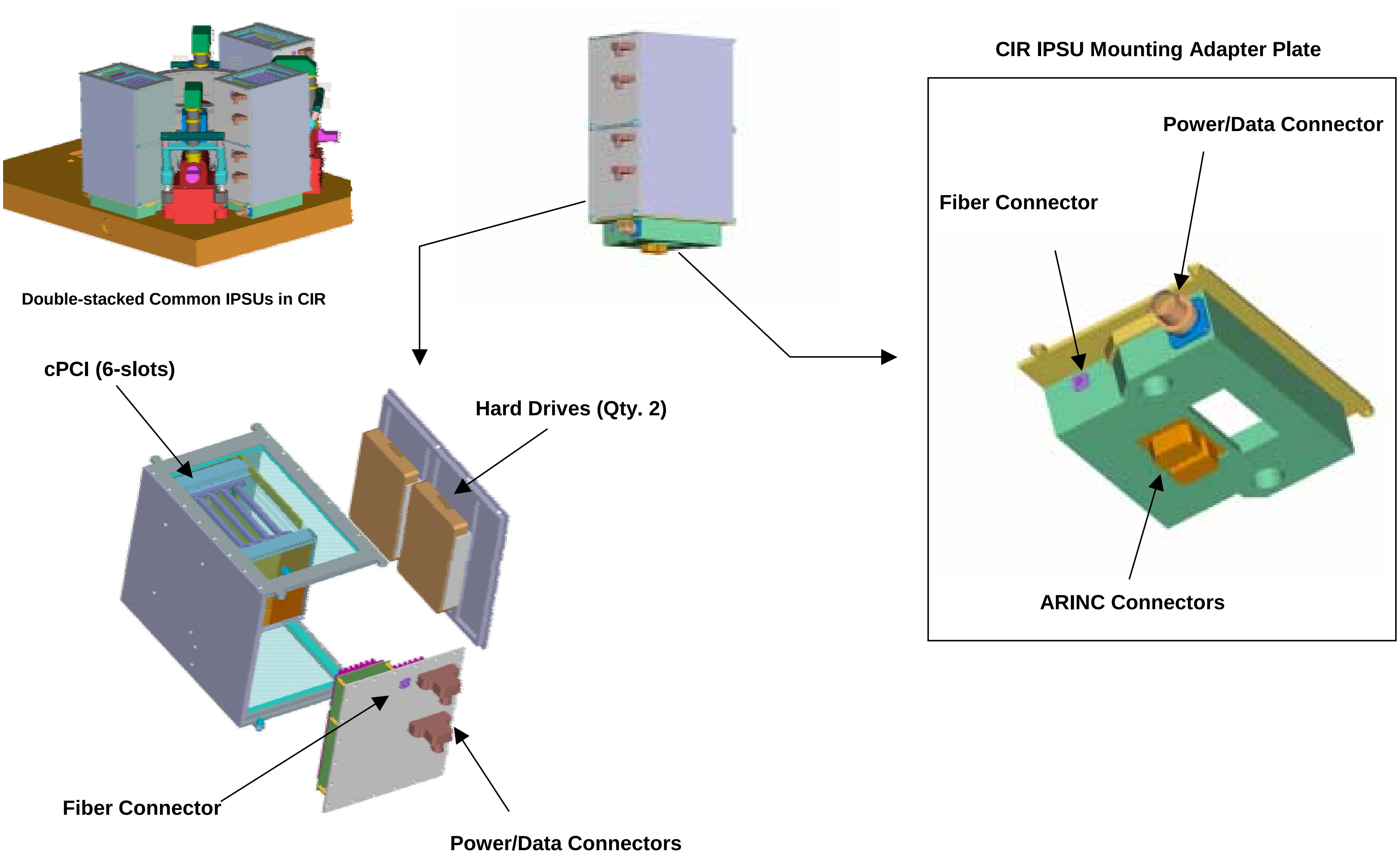
FCF Image Processing and Storage Unit (IPSU)-CIR Configuration Concept



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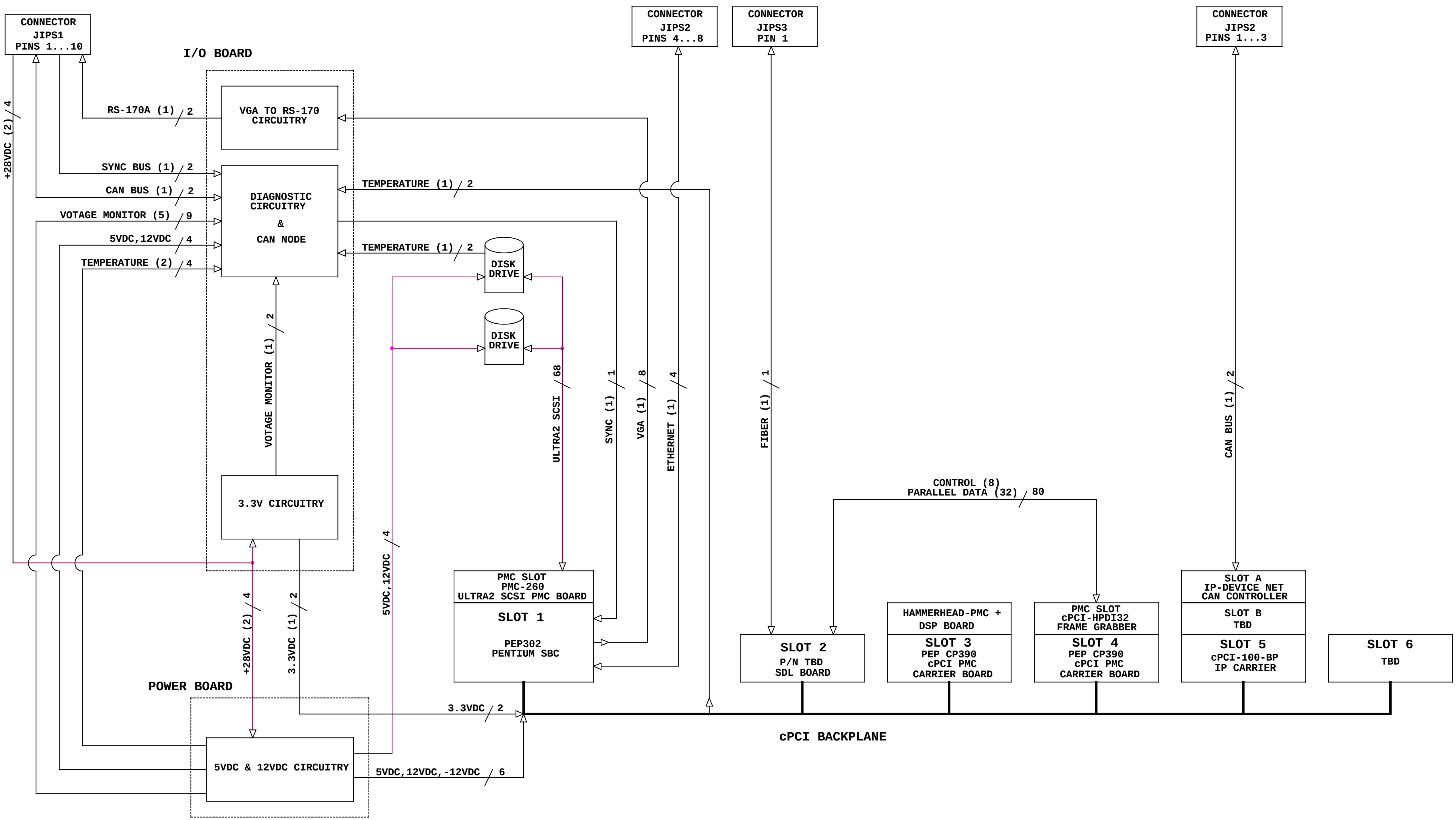
Common IPSU Block Diagram



5.2.6 Diagnostic Control Module (DCM)

Description

A Diagnostic Control Module (DCM) provides the control, power, cooling and mechanical alignment interfaces between the remainder of the modules in a diagnostic package and the Optics Plate. These modules are of a common basic design for all of the diagnostics with the exception of the Illumination Package that interfaces to an Illumination Control Module that has external interfaces that are identical to a DCM but different internal design characteristics. The module is attached to the Optics Plate using a removable Latch Handle that operates the attachment mechanisms. One handle will support all of the DCMs in the facility. A duct mates with the cooling port at the UML site. Direct access to the UML cooling port is provided at the top of the DCM. Alignment pins provide optical system positional repeatability on the Optics Plate. The mechanical interface to the rest of the modules is a kinematic mount that transfers optical system alignment precision from the Optics Plate without introducing stress loads. An optical fiber feed-through handles data coming from the IAMs. There is also provision for conducting analog video (RS170) to the UML.

5.2.6.1 Specifications

Electrical

- Motor Drive Current Limit:
    - Servo: 1.0 amperes maximum
    - Stepper: 0.25 amps per winding
- Camera Voltage: 28 volts
- Camera Current Limit: 4 amperes
- Optics Bench Interface: blind mate 2-bay ARINC connector
- Module interfaces:
    - Camera/motors: 100 pin miniature Airborn connector
    - Filter: 31 pin miniature Airborn connector

Mechanical

- Dimensions: 260mm (W) x 198mm (D) x 133mm (H)

System

- Cooling capacity for external devices: 60W at a pressure drop of 0.200 in. H2O
- Two CAN Bus connections are provided. One is dedicated to control of the DCM. The other is routed to the 100 pin Airborn connector.
- **RS232 communication is provided at the output for camera package control.**

Application Note

A maximum of four servo motors or four stepper motors or combinations of stepper/servo motors in pairs can be controlled simultaneously. Maximum total drive current is limited to 2 amperes.

The following figure illustrates the Diagnostic Control Module and Latch.

Diagnostic Control Module and Latch Mechanism

Representative Diagnostic Package

DCM

Latch Mechanism

Mounting Plate

5.2.7 Rack Closure Doors

The face of the FCF Racks is covered by a door composed of four segmented panels that can be opened separately along the length of the rack. Each of the two inner panels are hinged to the other panels and can fold up onto the outer panel. These combined segments can then hinge upward and downward approximately 92 degrees and extend out from the rack approximately 10.2 cm (4 in.) to allow full access to the internal FCF rack. The rack door incorporates the following features:

- **Rack stiffening and load distribution** during transport to orbit
- **Physical barrier** to provide containment of air thermal control and fire suppression mediums at the rack frontal boundary
- **Attenuation of acoustic emissions** from within the Facility Racks
- **Segmented panels** allow for physical and/or visual access to Facility assembly and package front panels
- **Attachment points** for rack-to-rack umbilicals

Potential pinch points, sharp edges, and so on, need to be removed or covered to prevent injury to the crew.

Life testing and/or analysis will be completed to verify that doors will function as expected and not become jammed in a position that can prevent rapid safing or egress of the crew during a rapid depressurization of the U.S. Lab Module.

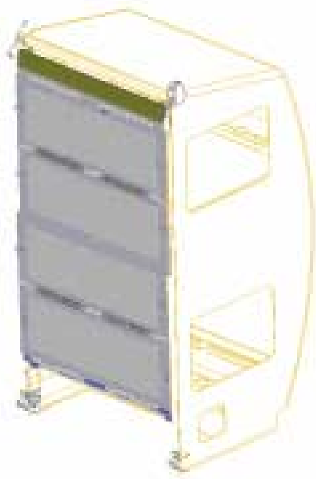
The rack door, if used as structural components of the FCF (and FCF as a whole), need to meet the structural requirements in NSTS 1700.7, SSP 57000 and 52005, and SSP 41017 (parts 1 and 2). All scenarios, including ground transport, launch, on-orbit transfer, and landing loads will be considered in the design.

Rack Door Switch

Each FCF rack door contains a limit switch. The two switches are connected in series, and wired to the IOP. When the rack doors are closed, both of the switches are in a closed position and a digital signal is received at the IOP. The IOP is then aware that the rack doors are closed and can enable the power to the various illumination sources via the 1553B communication link to the EPCU.

The rack closure doors in the closed, and fully open configurations are shown in the following figure.

FCF Rack Closure Door Features

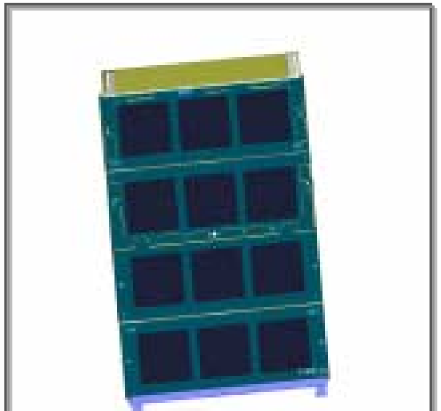


Fully Closed

Fully Open

Front

Frame and Panel Construction facilitates different panel combinations for Physical Access, Visual Access, and Externally-Mounted Features.



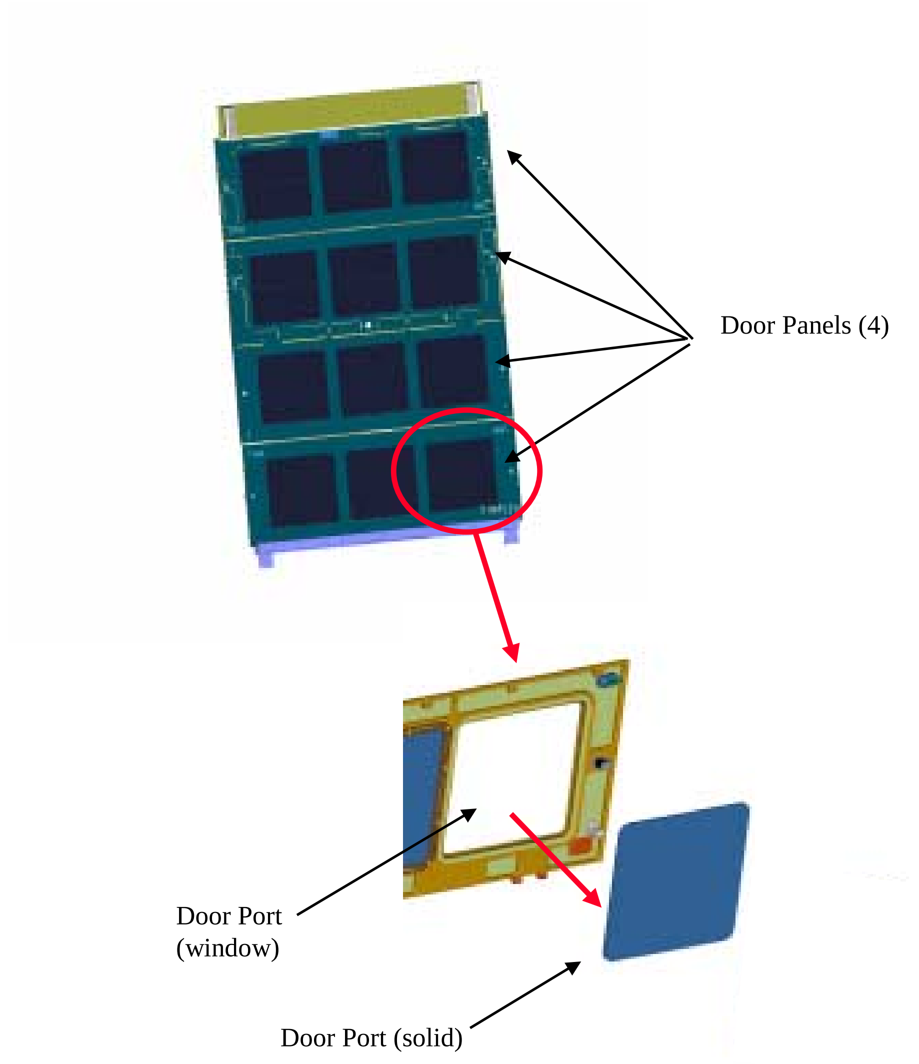
Rear

5.2.7.1 Rack Door Port Interface

The FCF Racks have removable ports in the rack doors as an alternative way of meeting potential future requirements for experiment package adjustments. The rack door consists of 4 door panels (2 panels per door), with 3 removable ports per panel (12 total). Replacing a door port is done by loosening the captive fasteners on the port. A solid port or interface port can then be mounted to the door.

The rack door port concept is shown in the following figure.

FCF Rack Door Port Interface Concept



5.2.8 FCF Optics Bench Slide Assembly

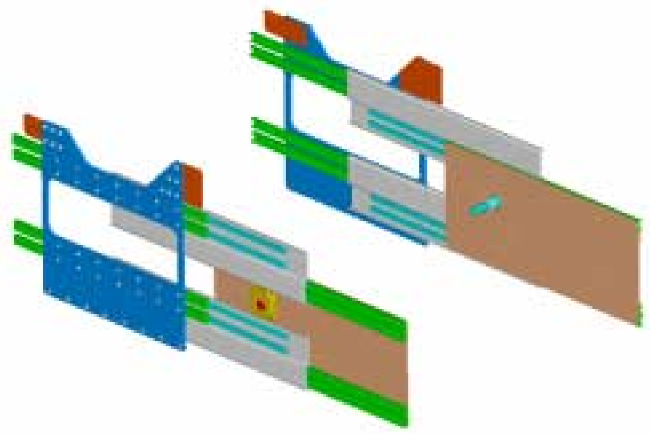
The basic function of the optics bench slide is to provide access to both sides of the optics bench for both experiment setup and maintenance of the various components on both sides of the bench. The slides and the pivot mechanism built into them and the optics bench allow the bench to translate a total of 78.7 cm (31 in.) from the locked operational position within the rack. After translation the bench can then be rotated downward 90° for access to the back of the bench.

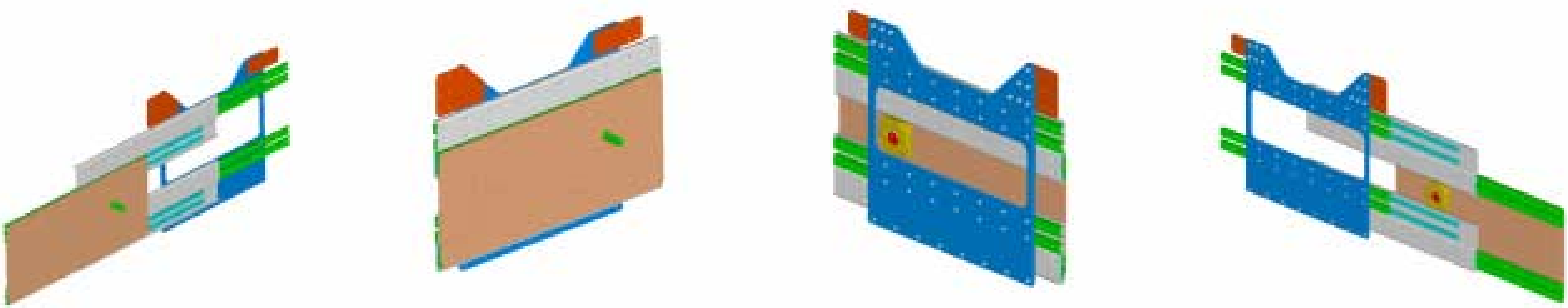
The face of the optics bench, the optics plate, is recessed about 50.8 cm (20 in.) from the front of the rack. The slides allow the front of the bench to be pulled out the 27.9 cm (11 in.) beyond the front of the rack for access to the front of the plate. The translation of the optics bench is designed to be a one-handed operation.

Translation of the bench is accomplished by first pushing the handle latch pins to release and extend the slide handle out in front of the slide and to unlock both slides for translation. The slide handle is located on the left slide in the handle housing. Squeezing the torsion spring bar on the slide handle and pulling the handle moves the slides linearly a distance of 78.7 cm (31 in.). Releasing the torsion bar at any time during the translation stops the optic bench via torsion spring clutches located within the slide mechanism. Once the bench is stowed in the rack, pushing the handle latch pins allows the slide handle to be pushed into the handle housing for storage.

The FCF optics plate slide mechanism is shown in the following figure.

FCF Optics Plate Slides Assembly





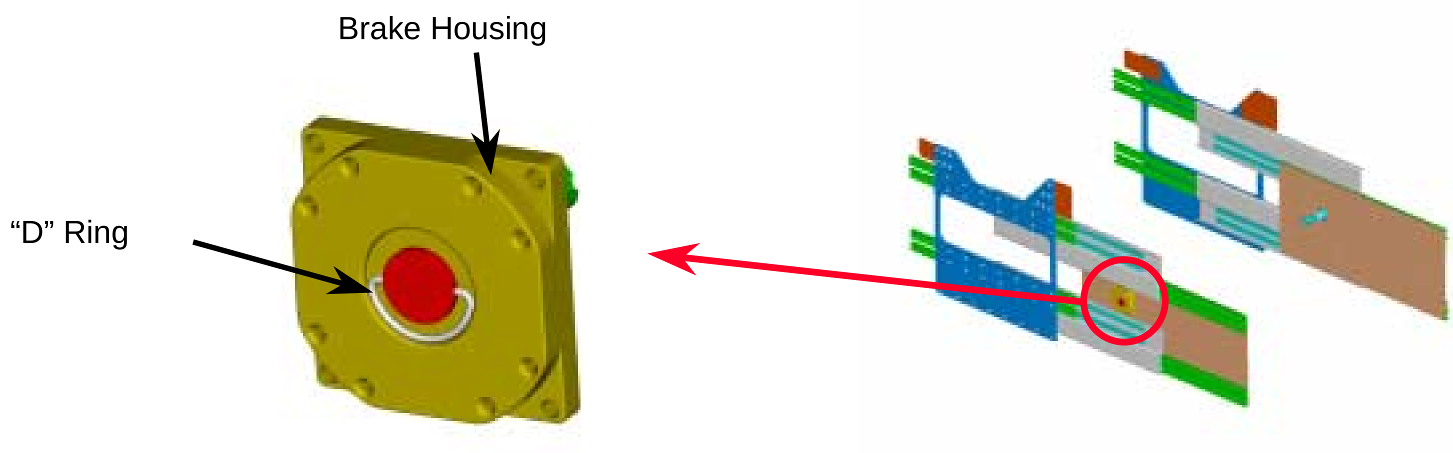
Inside Extended | Inside Retracted | Outside Retracted | Outside Extended

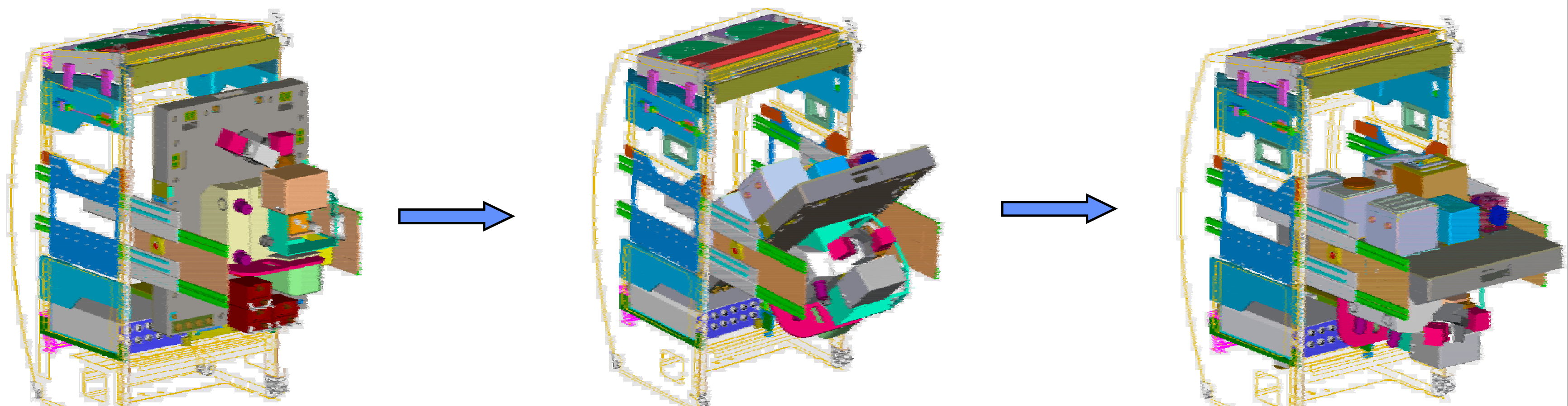
5.2.8 FCF Optics Bench Slide Assembly (concluded)

With the slides fully extended the optics bench can be rotated 90° by first turning a "D" ring on the brake housing located on the left slide assembly. This releases a latch pin inside the housing allowing the optics bench to be rotated through any angle up to 90°. When the desired angle of rotation is reached, rotating the D-ring (clockwise or counter-clockwise) activates the brake and stops the rotation.

The optics plate slide rotation mechanism is shown in the following figure.

FCF Optics Plate Rotation Mechanism





Optics Bench Rotation Operation

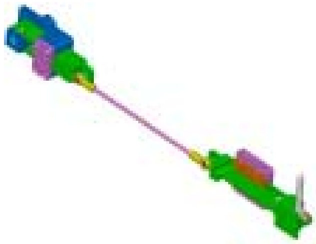
5.2.9 FCF ARIS Pin Assembly

There are two pin assemblies built into the FCF launch support plates. The additional lower pin assembly is mounted in the center post between the EPCU and IOP. These assemblies function as holding devices to hold the optics bench in place in the rack through the high loads caused by launch and landing of the shuttle. The pins will also be engaged during on-orbit when the optics bench is in the stowed position at the rear of the rack.

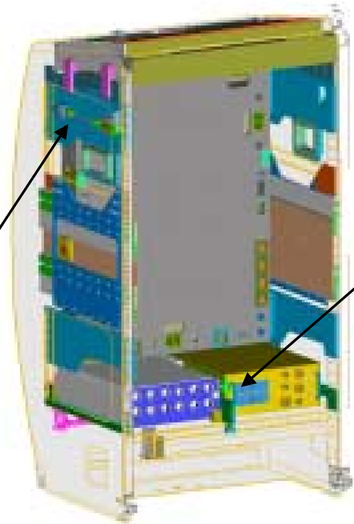
The three pin assemblies ensure that the optics bench will be completely contained in the rack by restricting movement in all 3 axis. The pin assembly functions by pushing/pulling a retractable handle (accessed by an open hole in the launch support side plate) which moves a yoke in the assembly. The yoke has a cam path that drives the pin into the optics bench when the yoke is moved towards the rear of the rack. A ball détent holds the yoke in the pin-extended/pin-retracted position.

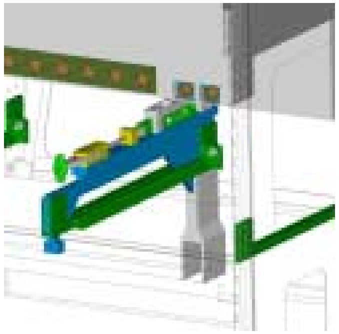
The FCF ARIS pin assembly is illustrated in the following figure.

FCF FCF Optics Plate Pin Assembly

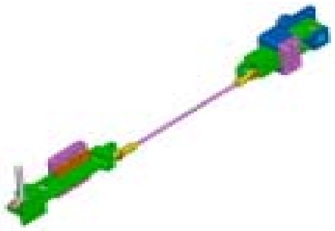


Left Pin Assembly

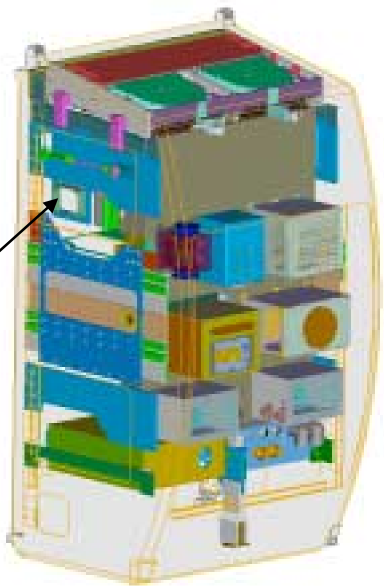




Center Pin Assembly



Right Pin Assembly



5.3 Metrics

The Fluids and Combustion Facility will be tracking key performance parameters that are allocated down to the package level over the course of the project based on the expected resources to be allocated to FCF.

The following page defines the FCF flight segment metrics.

FCF Flight Segment Metrics

Resources	CIR Resource Requirements	FIR Resource Requirements	SAR Resource Requirements
On-Orbit Volume	1 ISPR + .76 m^3 (26.6 ft^3)	1 ISPR + 1.0 m^3 (35.3 ft^3)	.60 m3 (includes stowage for 2 PIs and spares)
Up Mass	750 kg	750 kg	546.5kg (5 PI and spares)
Down mass	750 kg	750 kg	546.5
Up Volume	1.86 m^3 (66 ft^3)	1.6 m^3 (56 ft^3)	1.5 (5 PIs and spares)
Down Volume	1.86 m^3 (66 ft^3)	1.6 m^3 (56 ft^3)	3200 kwh
Energy (KWH)	3200	3200	180 (30 hrs/PI x 5 + 30 hrs for maint.)
Crew Time	180	180	41.1 terabits
Downlink (terabits/yr)	22.3	41.1	1.1E-04 terabits
Uplink (terabits/yr)	1.082 x 10^{-4} terabits/year	1.72X10(-4)	
Late/early access	NA	Yes	

Section 6 - FCF Software Design

6 SOFTWARE DESIGN

The FCF software is designed to be an integral part of the FCF Avionics Subsystem Components. As such, it makes up the FCF Command and Data Management Subsystem, and exists in the following units: IOP, EPCU, FCU, IPSU, FSAP, PI Electronic Enclosure, and the FCF and FIR Diagnostic Packages. The FCF software also has a ground component, in the Ground Integration Unit (GIU). The GIU contains both flight and ground software.

The major flight functions of the FCF software consist of the following:

- Command and control of both the rack and experiments
- Data management, including storage and retrieval
- Image processing
- Communication
- Status monitoring
- Trouble-shooting of flight segment problems
- Simulation of on-orbit operations
- Receipt of data and the initiation of commands from a remote site
- Remote FCF operations from the TSC
- Storage and archive of experiment data

The major ground functions supporting FCF consist of the following:

- Command and Control
- Telemetry
- Data Analysis

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6.1 DESIGN SPECIFICATIONS AND REQUIREMENTS

The FCF software is designed to support an environment in which to conduct sustained systematic combustion and fluids research under microgravity conditions. Toward this end, the FCF software must be:

- Modular in design, so that mission specific code, sequences, and parameters can be changed without reloading non-mission specific code, sequences, and parameters;
- Modifiable by the ground through the communication network available to the ISS; and
- Easily migrated to upgraded hardware and firmware.
- The FCF software must perform all command processing, control, data processing, data management, caution and warning, health and status monitoring, and timing functions associated with the FCF.
- Adjunct ground software consisting of command and control, telemetry and data analysis functions will provide the ground support teams the ability to control nearly every aspect of the FCF facility. The only exception will be any crew based functions such as bottle change-outs, etc.

A more detailed design description for FCF for the FCF software can be found in the FCF Software Requirements Documents and in the FCF Software Design Definition Documents.

6.2 PERFORMANCE REQUIREMENTS

The FCF software provides the following performance capabilities:

- Process and provide data, both to the on-board crew and the ground operations team and pis
- Respond to out of tolerance conditions
- Respond to the external environment
- Accept and respond to inputs and commands
- Support maintenance and troubleshooting operations
- Support reconfiguration operations

More detailed performance requirements for FCF software can be found in the FCF Software Requirements Documents.

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6.3 DESIGN FEATURES

This section discusses features of the operating system and application codes for the FCF software, and describes the FCF software architecture, operating modes, and handling of fault detection and isolation.

6.3.1 Operating System Code

The FCF software environment includes a real-time operating system. All FCF units where application software is running will utilize VxWorks®, a development and execution environment for complex real-time and embedded applications. Three highly integrated components are included with VxWorks: a highly scalable real-time operating system which executes on a target processor; a set of powerful cross-development tools which are used on a host development system; and a full range of communications software options such as Ethernet or serial line for target connection to the host.

Features of VxWorks include multitasking with preemptive priority scheduling, intertask synchronization and communications facilities, interrupt handling support, watchdog timers, memory management, ANSI C-compatible I/O system, SCSI disk support, and TCP/IP support.

6.3.2 Application Code

The application code for the FCF will need to be able to support a variety of configurations and experiments over a ten-year period. To minimize the impact of the configurations to the software, it is important that the software be flexible enough to easily allow for configuration changes without requiring major reworking of the software.

To facilitate this goal, the FCF software utilizes COTS software in many areas.

6.3.3 FCF IOP

To take advantage of the benefits of object oriented software, the FCF IOP software will be written in C++. This will allow for a top down design approach where specific functions can be identified and categorized in a meaningful manner. This will not preclude the use of COTS software, which may be written in C or assembler.

The user interface software, which will be used by the crew to monitor and control the FCF, will be written. This will allow the crew to use a COTS browser on their laptop to load and run the software.

All Ethernet interfaces will be implemented in sockets.

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6.3.4 FCF EPCU, IPSU, and Diagnostic Packages

Application code for these units will be written in C++. This will allow the code to be optimized for speed, and will facilitate writing low level I/O drivers and interfacing with existing single board computer support packages.

6.3.4.1 Common Image Processing and Storage Unit (Common IPSU) Software

The Common Image Processing and Storage Unit (Common IPSU) is a separate system from the Avionics Packages since its function consumes enormous quantities of computer resources. Each digital camera has an IPSU dedicated to it for image processing and storage.

The software of the Common IPSU will accommodate fluid and combustion experiments. It is an expandable system in that experiment specific software may optionally be executed on the system. For instance, the software allows a PI to implement a custom image-processing algorithm.

The software of the Common IPSU is responsible for image analysis and closed-loop imaging. A cutting edge SHARC DSP board performs core the image processing, which minimizes host processor requirements. This board contains a separate software system that must interface with the host processor's software. The DSP software design is object oriented with UML, but is limited to 'C' in implementation due to the unavailability of a SHARC C++ compiler. The DSP program does not have an operating system since its multi-tasking requirements are not complex.

The host processor's software is written in C++ and run under VxWorks multi-tasking operating system.

6.3.4.1.1 Common IPSU Functions

The Common IPSU has many inherent functions beyond image processing and storage. This section lists and describes each.

Image Acquisition The Common IPSU is responsible for image acquisition. The hardware, and therefor software, accommodate a variety of camera's. Any digital camera with RS422 output is supported, that has vertical and horizontal synchronizing output lines. The pixel resolution can range from 8 bits to 16 bits, inclusive. The package can support incoming image rates greater than 70 MB/S.

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Image Diagnostics Functionality of the Common IPSU supports the following science diagnostics.

*Closed Loop Functions*Auto Focus

- Automatic Positioning and Tracking
- Auto Exposure

*Image Analysis Functions*Real-time Compression

- Image Cropping
- Frame Averaging
- Feature Extraction
- Centroid Calculation
- Histogram Generation
- Spatial Domain Filtering
- Spatial Frequency Analysis
- Logical Operations

Other Diagnostics

- Event Triggering
- Synchronization of camera

Power On Self Test The Common IPSU is capable of performing self-tests at power up to assure the system's hardware is operating properly. Devices such as memory, DSP board, CAN controller, and frame grabbers are exercised before any experiment operations are allowed to start.

CommunicationsOn FIR, the Common IPSU communicates with the IOP, FSAP, PI FSAP, and the DCM associated with the IPSU's camera. Communication means are Ethernet and CAN bus. The Ethernet interface is VxWorks' API. The CAN interface is a proprietary C++ implementation, which is the same as used on the FSAP.

The first communication use with the IOP loads the VxWorks kernel software at boot-up. It must accept commands from the IOP and reply back. It must be able to download stored image data to the IOP, which has removable hard drives. Additionally, the IOP can download image data to ground. The Common IPSU may be a pass-through router of commands for a DCM from the IOP.

The FSAP, PI-FSAP, and CIR SAP for combustion support, supply the diagnostics commands for the Common IPSU. For example, enabling image archiving of every 4th image.

Communication with a DCM is via CAN bus. Its connection is to support configuration local to the camera (such as a binning mode) or commands for movement of the gimble or translation stage.

The Common IPSU software must be able to write images to the local video controller which is connected to a scan converter. The scan converter creates an analog signal of the image which can then be downloaded by way of the IOP.

Test Point Operations Test Points are necessary to complete experiment test runs and make decisions during an experiment run. Test Point operations use image analysis data to make control decisions and generate commands to the diagnostics package.

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Built-in features of each device interface are FCF provided.

SHARC Based DSP Board Performs Image Processing

- Core processing algorithms written in assembly language.
- SIMD mode utilized, which double performance.
- Interrupts used for bi-directional communication between host processor and DSP processors.

CAN Controller Direct communication to DCM for closed-loop camera control.

- Interrupt level notification of incoming CAN messages.
- Software and hardware filtering of message IDs.

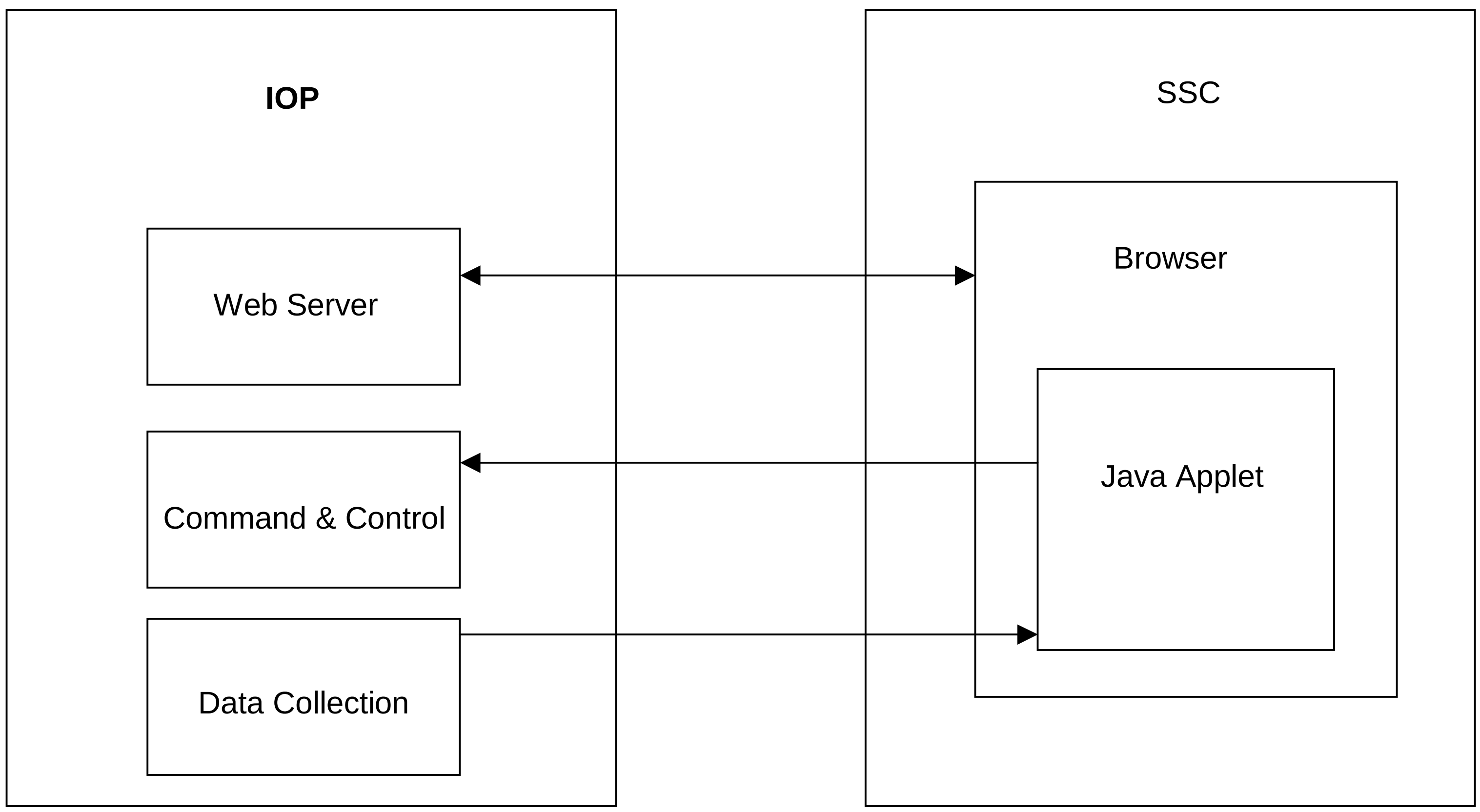
6.4 SOFTWARE ARCHITECTURE DESCRIPTION

This section describes the software architecture for the FCF Avionics components.

The interface between the FCF IOP and the Station Support Computer is illustrated in the following figure. The Web Server is an HTTP Server that allows the SSC to utilize a COTS browser for its interface software. The COTS browser is started on the SSC by a crew member. The crew member enters the URL of the FCF IOP and is sent an HTML document. The HTML document contains an HTML tag that specifies the user interface software, a Java applet. The browser starts executing the applet after it is transmitted from the FCF IOP. The applet opens a separate connection on the Ethernet, which facilitates the passing of commands and data between the FCF IOP and the SSC. The interface between the browser and the Web Server is implemented in Hypertext Transfer Protocol (HTTP). The interface between the Java applet and the FCF IOP software is implemented in sockets.

The following figure illustrateds the FCF IOP/SSC interface..

CIR IOP/SSC Interface



The IOP will have three interfaces to the ISS. They are the High Rate Data Link (HRDL), Medium Rate Data Link (MRDL) and Low Rate Data Link (LRDL).

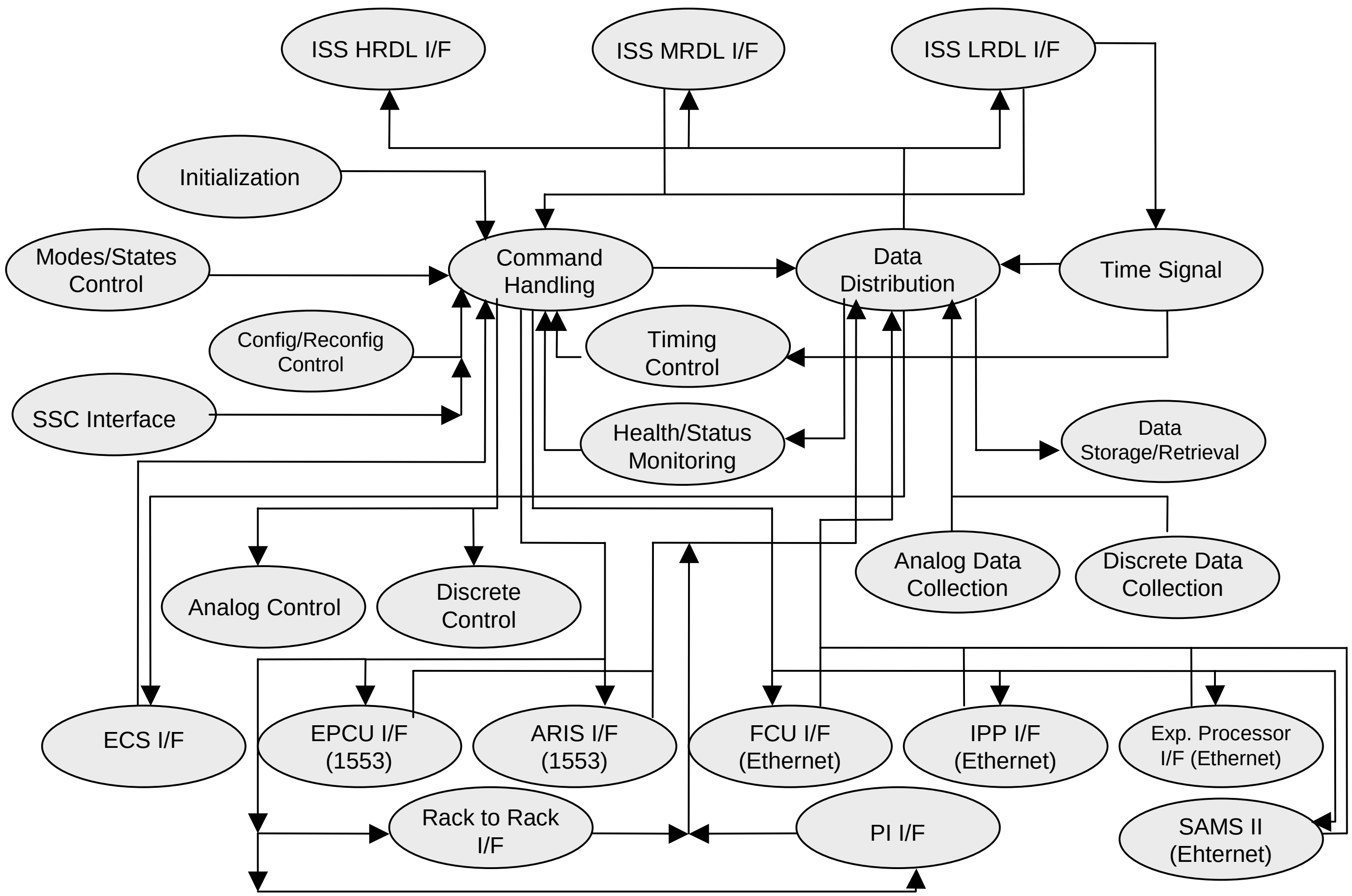
The HRDL is a FDDI network, which will be utilized to downlink data files to the ground.

The MRDL is an Ethernet network that will be utilized to interface to other ISS payloads (e.g. SAMS) and to downlink real-time data. The SSC will typically have a direct connection to the IOP over the FCF rack Ethernet. The interface to the SSC will be implemented with sockets, which will facilitate the passing of commands and data between the SSC and the FCF rack. The real-time data will consist of CCSDS data packets encapsulated in 802.3 message packages. These packages will be transmitted to the ISS, which will transfer the data to the ground.

The LRDL is a MIL-STD-1553B network interface. The interface will be utilized to transmit commands to the FCF rack either from the crew's SSC or from the ground. Emergency, Warning, Caution and Advisory (EWCA) data will be transmitted to the SSC when requested. The IOP will be a remote terminal (RT) on this bus.

The following figure diagrams the IOP software architecture.

FCF IOP Software Architecture Diagram (CSCs)



The IOP will have interfaces to the Electric Power Control Unit (EPCU) and the Active Rack Isolation System (ARIS) over MIL-STD-1553 buses. Each of these interfaces will be implemented on the same bus. The IOP will be a bus controller (BC). The EPCU and the ARIS will be RTs.

The FOMA Control Unit (FCU), Image Processing Package (IPP) and SAMS II will interface with the IOP over Ethernet. The Ethernet will be an intranet, constrained to FCF. The logical interface between the IOP and both the FCU and IPP will be implemented with sockets. Any Experiment Processor that may be installed in the FCF rack will communicate with the IOP over this Ethernet network.

Command Handling is responsible for initializing the FCF IOP software and routing commands to their roper destinations. It performs command queuing, verification and validation. It checks commands against the current state and mode of the FCF rack to verify that it is allowed to execute. It will provide control for configuration and reconfiguration of the FCF rack. It has a set of priority command queues, which will allow high priority commands to preempt lower priority commands. It will provide command status to Data Distribution.

Data Distribution is responsible for collecting data from the external interfaces, time stamping the data and then making it available for wherever it is needed.

Analog Data Collection is responsible for acquiring (sampling) data from the A/D modules (typically, temperature and pressure data) and transferring that data to the Data Distribution process.

Analog Control is responsible for receiving discrete control signals from the Command Handling process and transferring those signals to the D/A modules that are providing analog control signals to external effectors.

Time Signal keeps the clock on the FCF IOP in sync with the ISS time. The time is used to time stamp data and is used in coordinating any timing control needed by Command Handling.

Data Storage and Retrieval is used to access the SCSI disk drive.

Executable software, FCF html documents and FCF data will be located on the disk.

Health and Status Monitoring is responsible for checking for any off-nominal conditions and generating the necessary commands to handle the situation.

ECS I/F is the interface to the FCF Environmental Control System (ECS). It monitors ECS data and generates any commands to control the FCF environment.

A SAMS triaxial sensor head will interface to the IOP via a serial (RS-422) connection. The FCF SAMS process will convert the incoming serial datastream to a series of ethernet packets for downlink via the ISS MRDL interface. The SAMS process will also accept commands from the Command Handling process for affecting the SAMS sensor head.

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6.5 OPERATING MODES

FCF software is designed to operate in several different operating modes that could occur. These modes include:

- experiment operations
- anomaly resolution
- software maintenance/upgrade

6.5.1 Experimental Operations

During this operating mode, the FCF Flight Segment software will be operating the experiment, while the PI monitors progress at the TSC. During this period, data is being downlinked from the FCF to the ground.

6.5.2 Anomaly Resolution

During this operating mode, the ground team may attempt to diagnose a Flight Segment problem using the Ground Integration Unit, which must be configured identically to the Flight Segment.

6.5.3 Software Maintenance/Upgrade

During this operating mode, the FCF software will be undergoing maintenance or upgrade in some or all of the units in which it resides. System software maintenance and upgrade will occur less frequently, while experimental software maintenance and upgrade will probably be performed on a regular basis. New software loads will be uplinked as files through the ISS communication system to the FCF, where they will be verified and routed to the appropriate processor.

6.6 FAULT DETECTION/ISOLATION

The FCF IOP monitors the health and status of the FCF Avionics subsystems, including itself. It receives health and status data from each subsystem, and provides health and status data, and generates caution and warning messages for distribution to the crew and ground.

The FCF IOP has the capability of checking for, detecting, and isolating faults to the on-orbit repairable level without removal of equipment from its operating position.

6.7 SOFTWARE QUALITY ASSURANCE/CHANGE CONTROL

The Software Quality Assurance and Change Control requirements are specified in the FCF Software Management and Development Plan, FCF-PLN-0051.

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Chapter 7 – Supporting Engineering

7 SUPPORTING ENGINEERING

7.1 DESIGN RELIABILITY

In the design of equipment, appropriate reliability design techniques are being utilized to identify potentially critical failure modes and either eliminate these modes or minimize their impact. During the preliminary design phase, reliability criteria were established to define required failure tolerance goals. These primary reliability criteria include, but are not limited to, the following:

- The hardware must be capable of continuously performing between 5 and 10 combustion experiments per year.
- The FCF hardware, with scheduled and preplanned maintenance, must have a service life expectancy of at least 10 years without major refurbishment.
- On-orbit hands-on preparation and maintenance of the entire FCF should require less than 8 person-hours per week.
- For the life of the hardware, the FCF must accommodate the range of temperatures, pressures, and compositions typical of modern combustion science experiments.

Specific quantitative reliability criteria, such as a specific Mean Time Between Failures goal, were not imposed or required on this program. Rather, FCF is required to have the reliability needed to meet the experiment throughput performance requirements stated in Chapter 1 of the SRED.

Data resulting from Failure Modes and Effects Analysis (FMEAs) will be utilized to verify implementation of the criteria and to identify all critical failure modes. The FMEA shall also be used to determine Single Point Failures (SPF) and as justification for retention of the SPF where they cannot be eliminated.

7.1.1 Design Features

Design of the FCF hardware is guided by the constraint to utilize standard parts and materials consistent with man-rated hardware. When possible, spacecraft-proven components and parts will be used. Hardware items such as static sensitive parts and high power dissipating parts will be identified as critical items, subject to additional visibility and controls. (Note that these types of parts are not anticipated for use in the FCF hardware).

Specific hardware design features which contribute to increased system reliability include the following:

- Using a “global” approach to system reliability; this considers the reliability of lower level parts as well as key components.
- Designing major component based on the ORU philosophy (all major components except the Optics Bench).
- Maximizing the size of O-Ring seals for robust design.
- Tool-less access to the FCF for servicing and experiments.
- Minimizing the total number of parts and pieces.
- Minimizing “buried” designs; incorporating open and easy access to all major components.
- Using captive fasteners and self-sealing quick disconnects.
- Using proprietary coatings to ensure that moving surfaces do not stick or bind.
- Selecting high reliability EEE parts.

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7.1.2 Failure Protection

For this discussion, failure protection refers to the design features which are intended to reduce premature failures in FCF hardware design. The following types of failure protection features have been incorporated into the FCF hardware design.

- Computer-based automatic fault detection.
- Use of a two fault tolerant design for selected functions.
- Use of high reliability EEE parts.
- Materials selections and applications are compatible with all expected operating environments.
- Pressure ratings are not less than 1.5 time the maximum design pressure (MDP).
- System design utilizing off-the-shelf parts with proven capability (where practical).
- Using fused power transmissions to protect wiring and motors against overvoltages and power spikes.

7.1.3 Evaluations

The design continuously underwent a review of user needs in order to eliminate parts and components where practical. Reductions in total numbers of parts reduces the number of potential failures and thereby increases the overall reliability of the system. Design studies and trade-offs were performed in order to optimize the balance between hardware features, functions, cost, reliability, and complexity.

The design incorporates built-in redundancy in critical areas. For example, there are multiple shutoff capabilities in pressurized lines; the Optics Bench has multiple locking mechanism features; and the EVP has redundant blowers for purge and cleanup of the Combustion Chamber and its associated lines.

7.1.4 Single Point Failures

Where the FMEA identifies single point failures, alternate designs which result in the elimination of single point failures (SPF) will be considered. Where it is not feasible to eliminate the SPFs through design modification, failure risk reduction will be evaluated (such as improvement in quality of parts, reduced operating environments, or usage application). In any case, credible failures shall not compromise PI experiment throughput or FCF availability requirements.

7.1.5 Limited Life Items

Limited life items are those items whose expected failure-free life is less than the planned mission life. Some limited life items may be used in the design as a result of unique performance characteristics required for the project, or as the result of design constraints such as weight, volume, cost, or sole supplier status. In such cases, periodic inspection, testing, maintenance, or replacement of limited life items may be necessary to assure successful continuation of a mission. Once the limited life items list is developed, the expected failure-free life of an item and other limited life item data can be considered in relation to functional criticality. A decision can then be made with respect to the most effective methods of control.

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7.2 DESIGN MAINTAINABILITY

Maintainability is a characteristic of the FCF that reflects the ease involved in performing maintenance activities. The goal is to minimize the crew time and other resources (tools, test equipment, etc.) required to perform preventive maintenance. It is the intent of the FCF project to minimize the amount of contingency (unplanned) maintenance by conducting regular, preplanned and scheduled maintenance.

7.2.1 Design Features

The design features that allow the FCF to meet the desired science throughput also make the system much easier to maintain. Some maintainability features incorporated are:

- Use of the Orbital Replacement Unit (ORU) concept
- Modular diagnostic packages
- Modular electronics (PI specific) packages
- Optics bench mounting of components for easy access
- High design reliability relative to duty cycle
- Board level replacement for FCF avionics (IOP and FCU)
- Use of cartridge valves
- Self-sealing quick disconnects for removable components

7.2.1.1 On-Orbit Maintenance

On orbit maintenance of the FCF will center on the removal and installation of ORUs. Each item designated as an ORU will require limited crew time to install and check out. Standard ISS tools will be used for all on-orbit maintenance.

Maintenance of ORUs on orbit (intermediate level maintenance) may be used for cases where several ORUs contain a common component that has some expectation of failure during the deployment of the ORUs. Another consideration for intermediate level maintenance is whether upmass savings offset the expenditure of crew time to accomplish the repair. Intermediate level maintenance will require the ORU to be removed from the FCF to a suitable work area.

7.2.2 Spares

Logistics Support Analyses (LSA) will be performed on FCF systems to establish spares candidates, quantities, and additional data to support spares decisions. During LSA, a step by step Maintenance Task Analysis (MTA) will be performed in response to the failure modes during which the required maintenance resources, including spares, are identified. Resupply and Return Analysis will be performed on flight hardware and support equipment to identify the quantities of assets required. On-orbit spares types and quantities will be driven by on-orbit stowage and upmass/upvolume limitations. Selection priorities will be based on ORU criticality and reliability. Ground spares quantities will be determined by analyses, with a goal of at least one spare available for ground control and training items at the replaceable unit level.

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7.3 DESIGN SAFETY

The FCF was designed considering the requirements of NSTS 1700.7, Rev B, *Safety Policy and Requirements for Payloads Using the Space Transportation System*, NSTS 1700.7, ISS Addendum, *Safety Policy and Requirements for Payloads Using the International Space Station*, and the documents imposed by them. The design was assessed for hazards using standard safety analysis techniques. The hazard analyses, with detailed information on the hazards and their control, were compiled into a report entitled *FCF Phase 0/1 Flight Safety Data Package* (FCF-PLAN-A-003). This report should be consulted for specific information on FCF hazards.

7.3.1 Hazard Evaluation Methodology

Hazard evaluations can be generic or unique. During the early stages of design development, when system hardware design is not fully matured, generic hazards are evaluated as an initial step in the progressively more detailed hazard analysis process. System-unique hazards are then identified and analyzed as hardware design definition matures.

For generic hazards, the analysis is recorded using Johnson Space Center form (JSC Form) 1230, *Flight Payload Standardized Hazard Control Report.* This form identifies approximately 15 hazard descriptions which tend to be common to many hardware systems and establishes standard controls for them. The generic hazards are:

- Structural Failure
- Structural Failure of Sealed Containers
- Sharp Edges
- Shatterable Materials
- Flammable Materials
- Materials Offgassing
- Non-Ionizing Radiation
- Lasers
- Battery Failure
- Touch Temperature
- Electrical Power Distribution
- Ignition of Flammable Atmospheres in the Payload Bay
- Rotating Equipment
- Mating/Demating Power Connectors
- Contingency Return/Rapid Safing

System-unique hazards typically do not fall neatly into one of the 15 groups listed above. When this is the case, system-unique hazards are compiled on separate sheets and assigned an identification/tracking number. These sheets, called *Experiment Flight Hazard Report* sheets, are based on JSC Form 542B, describe the system-unique hazard, and recommend and define the hazard controls being implemented.

7.3.2 Safety Features/Controls

Detailed information on safety features and controls may be found in the Safety Data Package. Most of these features have been discussed previously in this document, such as two-fault tolerant triply redundant subsystems; electronic current limiting to prevent overloading and overheating of components; and fused solenoids.

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7.3.3 Maintenance Safety Considerations

During the life of the facility, a number of reasons may cause the hardware to need to be re-verified: Failed components, hardware or software upgrades, limited life item change out, or out-of-calibration limits are reached. When these occur, there may need to be a re-verification of the set point or safety feature. These are covered on a individual bases in the subsystem in which they occur. A limited life items list will be created for the FCF and will be maintained by the ground crew which monitors the system from the GRC Telescience Support Center (TSC). A list of items needing periodic calibration will be created and maintained by the ground crew, who will plan for expected hardware change out and calibration.

Either new hazard reports will be written to cover the on-orbit test or the applicable hazard reports from the baseline Safety Data Package will be part of the flight safety data package produced for each flight.

Reverification of the Pressurized Subsystem

There will be certain re-verifications which must be performed on orbit. These may be required periodically or when a component is changed out. Some components which require difficult or hazardous operations to certify will be changed out with ground certified units. These will be identified at Phase II of the program safety effort.

Special procedures for the crew will be provided which step through the verification so that it is safe. Currently no safety controls are envisioned to be overridden (i.e., wiring back a relief valve so that a second relief valve can be tested) in order to test a control. Relief valves will be tested on the ground and certified. They will be installed with out re-testing on orbit .

7.3.4 Maintenance Safety Considerations

The human-machine interface is being analyzed from a safety perspective. Document SSP 50005 is being used as a requirements document by the designers and the persons reviewing the design. Along with sharp edges and protrusions , other concerns being addressed include handle sizing, spacing, and placement to insure the crew will not be exposed to moving masses or pinch points; speed of motion of items to insure safe operating speeds; covering of pinch points; and sufficient space for access to prevent injuries.

7.3.5 Protective/Warning Devices

Protective/warning devices and methods incorporated into the FCF design include:

- Manual pressure indicators.
- Fused solenoids.
- A laptop computer which will display operating limits monitored by the IOP.
- Ground software which will monitor pressure levels, fluid levels, and voltages.

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7.4 QUALITY ASSURANCE

Quality assurance activities are initiated during the design phase to ensure that quality considerations have been incorporated into the hardware design and documentation. Quality assurance efforts will include examining hardware evolution during the design, production, in-process, and performance phases of the development process.

7.4.1 Design

Design and development documents requiring review and approval by Quality Assurance include engineering drawings, specifications, and selected reliability and safety documents. Quality Assurance shall review these documents to verify that quality characteristics and design and acceptability criteria have been considered and included in the documents and that hardware characteristics requiring special verifications have been identified.

In addition, hardware design will be evaluated for inspectability and producibility to ensure that the hardware can be readily produced/reproduced and evaluated. During this evaluation, hardware critical characteristics (i.e., those characteristics of the hardware which cannot be verified by inspection alone) are identified and flagged for special attention.

7.4.2 Production

Quality assurance will support the production phase of FCF hardware development by defining inspection criteria and hardware accept/reject criteria. In addition, quality assurance will participate in preparation and/or review of manufacturing and assembly procedures and process specifications and standards, should preparation of any be required.

7.4.3 In-Process

Activities during the build up and assembly of the FCF flight hardware include definition of inspection requirements, identification of critical inspection points, preparation of inspection procedures, preparation of assembly procedures, and preparation of any required work instructions.

7.4.4 Performance

During hardware testing and performance, quality assurance will provide support to the test engineering effort by:

- Preparing test plans/procedures and test criteria
- Defining test performance/tolerance limits
- Establishing test performance accept/reject criteria
- Identifying and controlling limited life items
- Preparing for and conducting hardware Acceptance Testing

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7.5 MANUFACTURING CONSIDERATIONS

Manufacturing and assembly functions have been considered in support of design, development, fabrication, assembly, and testing of the FCF. These are all preliminary evaluations and are based upon the current state of hardware design.

As part of the manufacturing planning activities, a producibility review will be conducted. This review will assess the following design characteristics and their impact on the manufacturing process:

- Tolerancing
- Ease of Manufacture
- Manufacturing Controls
- Process Controls
- Reproducibility
- Packaging, Transportation, and Storage

The objective of this review will be to ensure there are no “show stoppers” once the hardware manufacturing phase is underway.

7.5.1 Make/Buy Considerations

The manufacturing procurement and requirements planning activity will establish quality standards for all purchased and manufactured materials, articles, and services. This will include the following:

- Selecting qualified vendors.
- Transmitting quality requirements to suppliers and incorporating these requirements into purchase order agreements.
- Implementing procedures covering receiving inspection, vendor surveys, and, when required, source inspections for purchased articles.
- Making provisions for timely corrective action when nonconforming articles are found.
- Providing technical assistance to suppliers when necessary to achieve desired reliability and quality levels.
- Using suppliers on a Buyer-approved processor’s list and selecting products from a qualified products’ list, where applicable and feasible.

7.5.2 Critical Processes

Manufacturing and quality assurance will work closely to ensure timely identification and control of all critical processes. A critical process is a process that can have significant performance effects on:

- Hardware identified as critical on the critical items list.
- Hardware designated for fracture control.
- Hardware where design conformance and/or uniform, high quality cannot be insured by inspection alone.
- Processes that are new or unique in application to the FCF.

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7.6 RISK MANAGEMENT/MITIGATION

The FCF System, Risk Management will be accomplished through identification of risk, evaluation of impacts and implementation of corrective or controlled action.

- Identified areas containing risk:
  - Requirements (Identification, Definition, Interpretation)
  - Technology
  - Development
  - Manufacturing
  - Verification
  - Integration
- Impacts of risk:
  - Cost
  - Schedule
  - Technical (ability to meet customer needs)
  - Safety

Project risks will be assessed by evaluating the probability of risk factors (requirements, technology, development, manufacturing, verification, integration, etc.) and the consequences of risk (cost, schedule, and technical) in terms of ability to met customer needs. Risks can be summarized on an isorisk contour plot as shown on the facing page. This technique plots an assessed probability of failure against assessed consequences of failure. High risks occur when the probability of failure and the consequences of failure are high (0 - low, 1 - high).

Based on the risk assessment summarized by the isorisk plot, the development risks are identified in the facing table. These risks will be mitigated by breadboard hardware and software development activities.

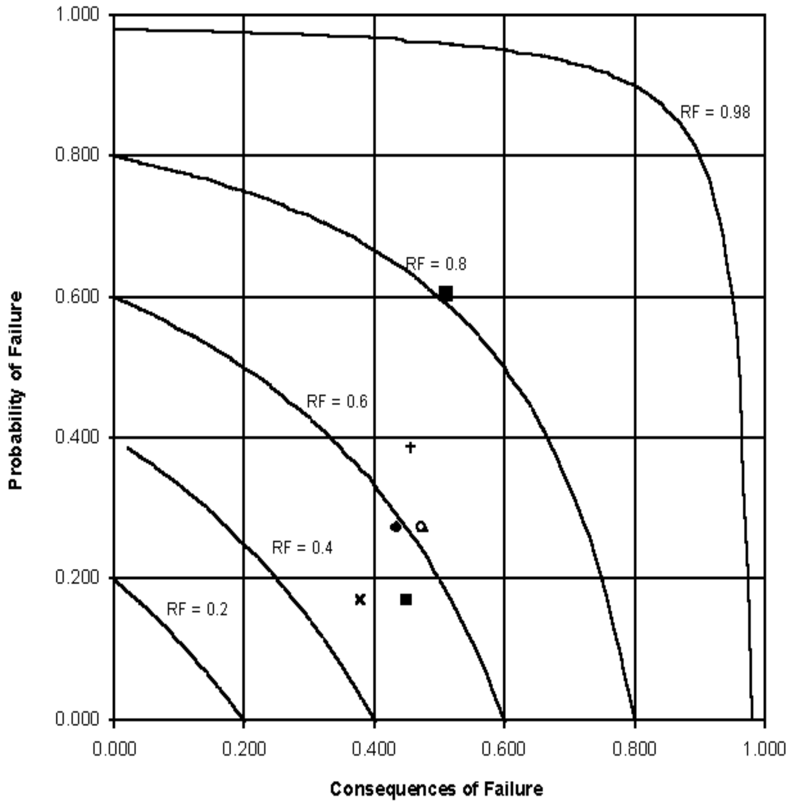
Architectural risks will be mitigated by utilizing design features and integration experiences from previous space experiments projects. These are summarized in the second table on the facing page.

7.6.1 Reliability and Maintainability (R&M) & Quality Assurance (QA)

The Office of Safety, Environmental and Mission Assurance (OSE & MA) will provide oversight to ensure that appropriate R&M & QA requirements are developed for FCF, and that the FCF is designed, fabricated, tested and operated to meet those requirements. A Product Assurance Plan tailored for FCF has been drafted based on Standard Assurance Requirements and Guidelines for Experiments (SARGE). The responsible organization for the design of the element hardware is responsible for implementing a reliability and quality assurance program, which meets the requirements.

The following figure illustrates the isorisk contour plot and risk mitigation activities.

Risk Management/Mitigation



- ● Command & Data Management
- ☑ Structures & Packaging
- ▲ Electrical Power
- ✕ Environmental Control
- ■ Software
- ❍ Combustion
- ✚ Fluids

ISO risk Contours for risk factor (RF) values between 0 and 1 are induced

General	
Engineering Model Development	
Shared Accommodations Rack Breadboards	
Standard Packages	Software User i/f Prototype
Power (EPCU)	CDMS
ECS (Fan/Heat Exchangers)	
Combustion Breadboards	
Optical Diagnostics	Gas Mixing System
Chamber Window & Changout	Chamber Package changout
Auto Positioning & Tracking	Liquid Crystal Tunable Filter
Fluids Breadboards	
HeNE Laser	Illumination
Nd: YAG	Video Data Management
Automated Positioning/Tracking	Focusing
Training Breadboards	
Computer Based Training	
Architectural Risk Mitigation	
Fuel Oxidizer Management Assembly	CM-1 Fluid Supply Package
Chamber	CM-1 Chamber

Chapter 8 – Utilization and Integration

8 UTILIZATION AND INTEGRATION

8.1 Mission Integration

The integration responsibilities of FCF are two-fold. First, FCF must integrate with the ISS. This integration process has been defined by the ISS Payloads Office and requires the development of a FCF-to-ISS Interface Control Document (ICD) and a FCF-to-ISS Payload Integration Agreement (PIA) with a specific addendum for every increment that FCF operates. This process ensures compatibility with the ISS vehicle accommodations, safety, and resources. To support this top-level integration function, a second process is necessary to integrate PI-specific hardware into the FCF. Interface and integration agreements between the PI-specific hardware team and the FCF will form the basis for this process. These agreements will outline requirements as well as roles and responsibilities. This process will be generic enough to accommodate all classes of PIs.

8.1.1 FCF to ISS Integration

With the release of the ISS Consolidated Operations and Utilization Plan (COUP) which describes the systems and utilization activities for the next 5 years, an ISS Payload Integration Manager (PIM) from the ISS Payloads Office (PO) was assigned to FCF. This assignment initialized customer interfacing and the development of the major FCF data products required to ensure proper integration of FCF with the ISS. These products are the FCF to ISS Payload Integration Agreement (PIA), the PIA addenda, the data sets, the FCF to ISS unique hardware and software Interface Control Documents (ICDs), the FCF unique Payload Verification Plan (PVP), and the Safety Data Packages.

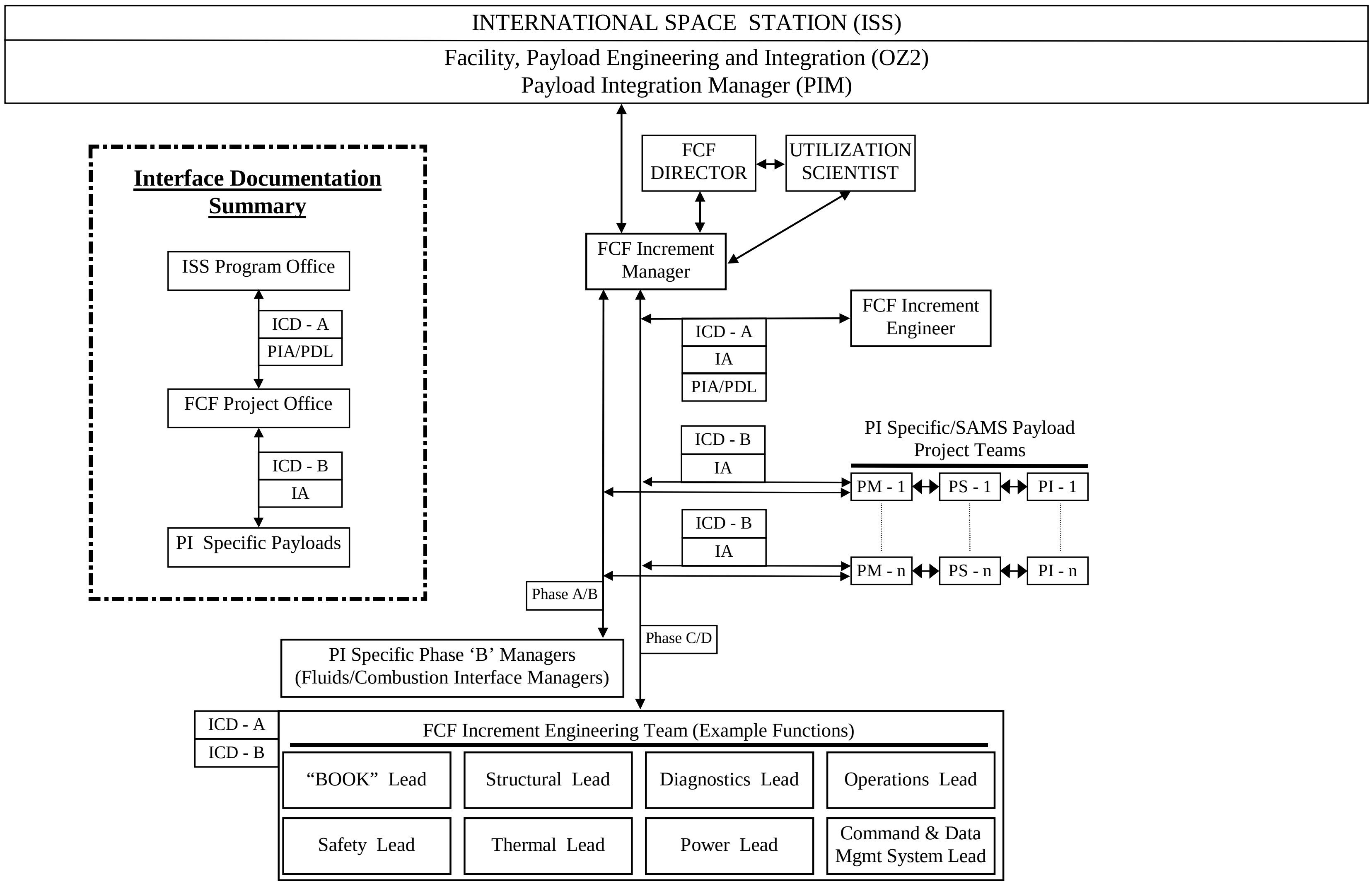
The FCF unique documents are based on ISS pressurized payload requirements found in the *Pressurized Payload Interface Requirements Document* (SSP57000), in the *Payload Integration Agreement Blank Book for Pressurized Payloads* (SSP 52000-PIA-PRP), and in the payload safety requirements documents (NSTS 1700.7 and the Addendum KHB 1700.7).

The FCF will develop their Unique ICDs and PVP through negotiations with the ISS PO Hardware and Software Engineering Integration Organization (OZ3). The PIA and associated data will be negotiated with the ISS PO Mission Integration and Planning Organization (OZ2). The Safety Data Packages will be worked directly with the Safety Office at JSC through the Payload Safety Review Panel (PSRP). All of these negotiations will be facilitated by the FCF PIM. These documents will be updated, as required, for each increment that FCF is operating and/or transporting logistics.

A Generic Payload Integration Template has been developed and will be used as the basis for the development of a FCF specific integration schedule. This schedule will contain the ISS integration product delivery dates such as program planning milestones, engineering integration milestones, operations integration milestones, flight milestones, safety milestones, and capability development milestones. The FCF schedule will be negotiated with the ISS PIM and then baselined. It then becomes the working schedule for all FCF to ISS integration activities.

The following page illustrates the Analytical Interfaces between the ISS Program and the FCF

FCF Payload to ISS Integration Overview



8.1.2 PI-specific Hardware Integration

The FCF Increment Engineering team starts working with the PI-specific Hardware team prior to the experiment RDR, The initial activities will focus on an exchange of information between the teams, with the PI-specific Hardware team providing an overview of the science requirements and the FCF providing an overview of the FCF. An FCF Accommodations Handbook will be available which describes the hardware and functionality of the FCF.

8.1.2.1 Phase A/B Integration

During this phase of PI-specific Hardware development, the interface managers will provide expertise on FCF interfaces to the PI-specific Hardware. This knowledge as well as generic FCF integration products will allow the PI-specific Hardware team as well as the FCF team to insure that all science objectives as well as ISS requirements are going to be considered in the PI hardware design. The PI-specific Hardware and Interface Managers will work together to develop science hardware concepts which effectively utilize the existing FCF capabilities while identifying potential upgrades to the FCF.

As the science hardware concepts are developed, the PI-specific Hardware Team will generate resource estimates and operations concepts to be used in the increment strategic and tactical planning activities. Some margin should be included in these estimates to account for the concept's fidelity and future growth.

This phase culminates in the experiment RDR at which time the science requirements will be presented and the PI-specific Hardware team and the FCF team will present hardware concepts intended to comply with those requirements. At this time, the FCF and PI-specific Hardware team will have developed a draft Integration Agreement and Interface Control Document which will outline the future responsibilities of the PI-specific Hardware and FCF teams as well as describes the particular FCF interfaces the PI hardware will require.

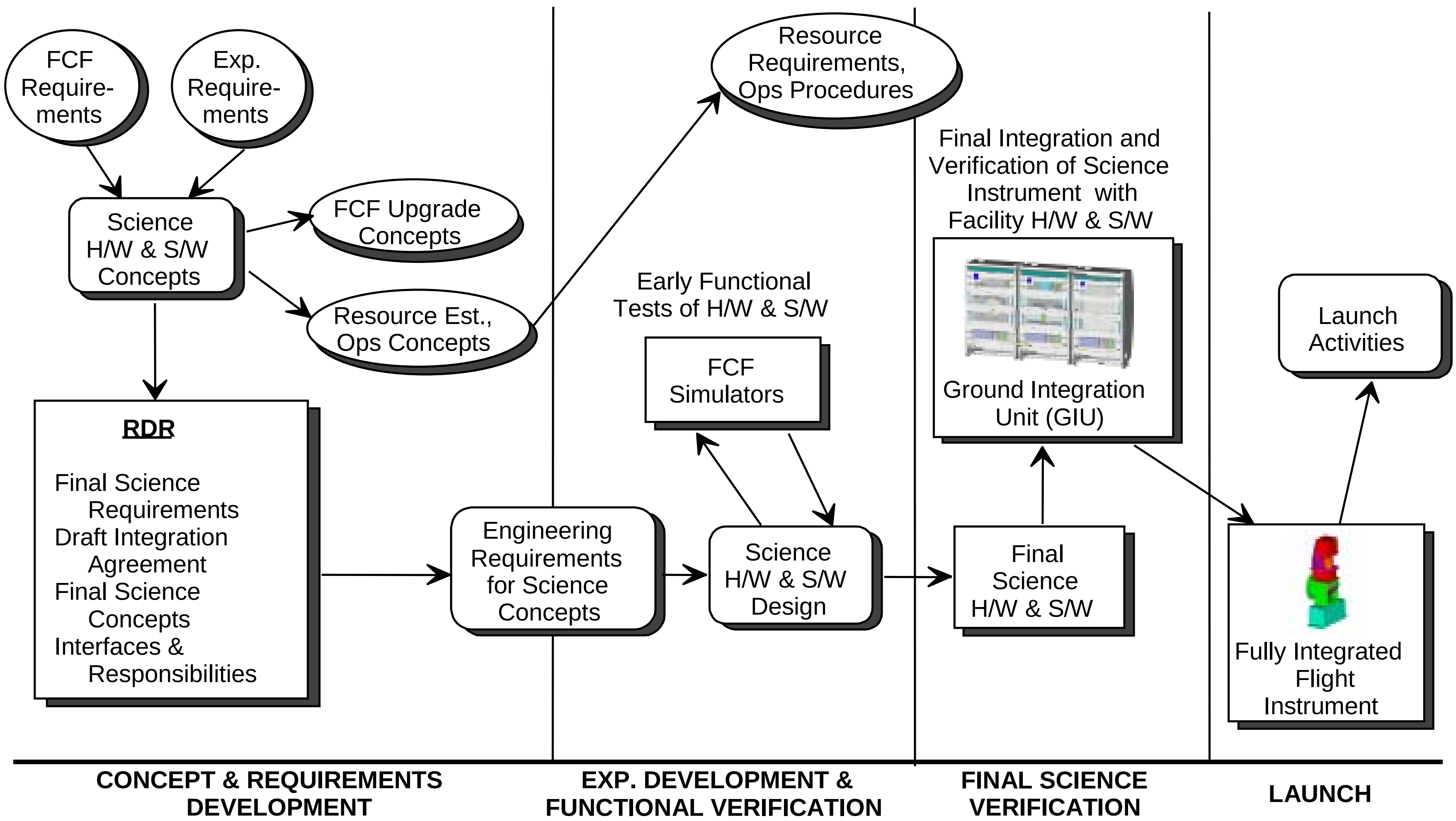
8.1.2.2 Phase C/D Integration

As the science hardware flight designs progress, the FCF Increment Manager, Increment Engineer and engineering team will work with the PI-specific Hardware team to ensure that the integrated system will meet the Science and ISS safety and integration requirements. Generic design analyses and test and verification plans will be provided to the PI-specific Hardware for completion. Once completed these plans will be used by the FCF to verify compliance with FCF and ISS requirements.

The FCF team will provide support for the PI hardware development. This support will be in the form of hardware and software simulators that the PI Teams can use for development of their own hardware. Software object libraries and device drivers will also be provided. If the PI-specific Hardware requires software drivers that do not currently reside in the FCF library, they will be provided if the driver can be used for an FCF upgrade. The FCF Engineering Model will also be made available to the PI Teams during PI Hardware development.

The following page defines the Top Level FCF to PI Integration Process.

Science Hardware Integration



When the science hardware has been built and tested, and the PI-specific Hardware team is satisfied that the hardware performs as designed, the experiment hardware and software will be integrated into the FCF Ground Integration Unit for final integration, testing and verification.

After the hardware has been verified, it will be packaged by the FCF logistics team and sent to KSC for launch site processing. This includes visual inspection of the science hardware and packaging into the logistics carrier for transportation to the Space Station.

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8.2 Logistics and Maintenance

This section describes the FCF's Integrated Logistics Support and maintenance activities which will be performed during the development, testing and operational phases of the project. Logistics Support Analyses (LSA) will be performed on FCF systems to establish spares candidates, quantities, and additional data to support spares decisions. During LSA a step by step Maintenance Task Analysis (MTA) is performed in response to the failure modes during which the required maintenance resources, including spares, are identified. Resupply and Return Analysis will be performed on flight hardware and support equipment to identify the quantities of assets required

On-orbit spares types and quantities will be driven by on-orbit stowage and upmass/upvolume limitations. Selection priorities will be based on ORU criticality and reliability. Ground spares quantities will be determined by analyses, with a goal of at least one spare available for ground control and training items at the replaceable unit level.

Support Equipment - Requirements reviews for SE shall be conducted to assure that requirements are defined prior to initiating a preliminary Support Equipment Item Requirements and Description (SEIRD) document. A commonality assessment is then performed to determine if existing or modified equipment could meet the requirement.

8.2.1 Maintenance

Maintenance support for the FCF will be provided through a four-tier maintenance system:

On-orbit maintenance will be limited to the removal and replacement of Orbital Replacement Units (ORUs), with some cleaning, calibration and sub-ORU parts replacement as justified by the Repair Level Analysis. Standard ISS tools will be used for all on-orbit maintenance.

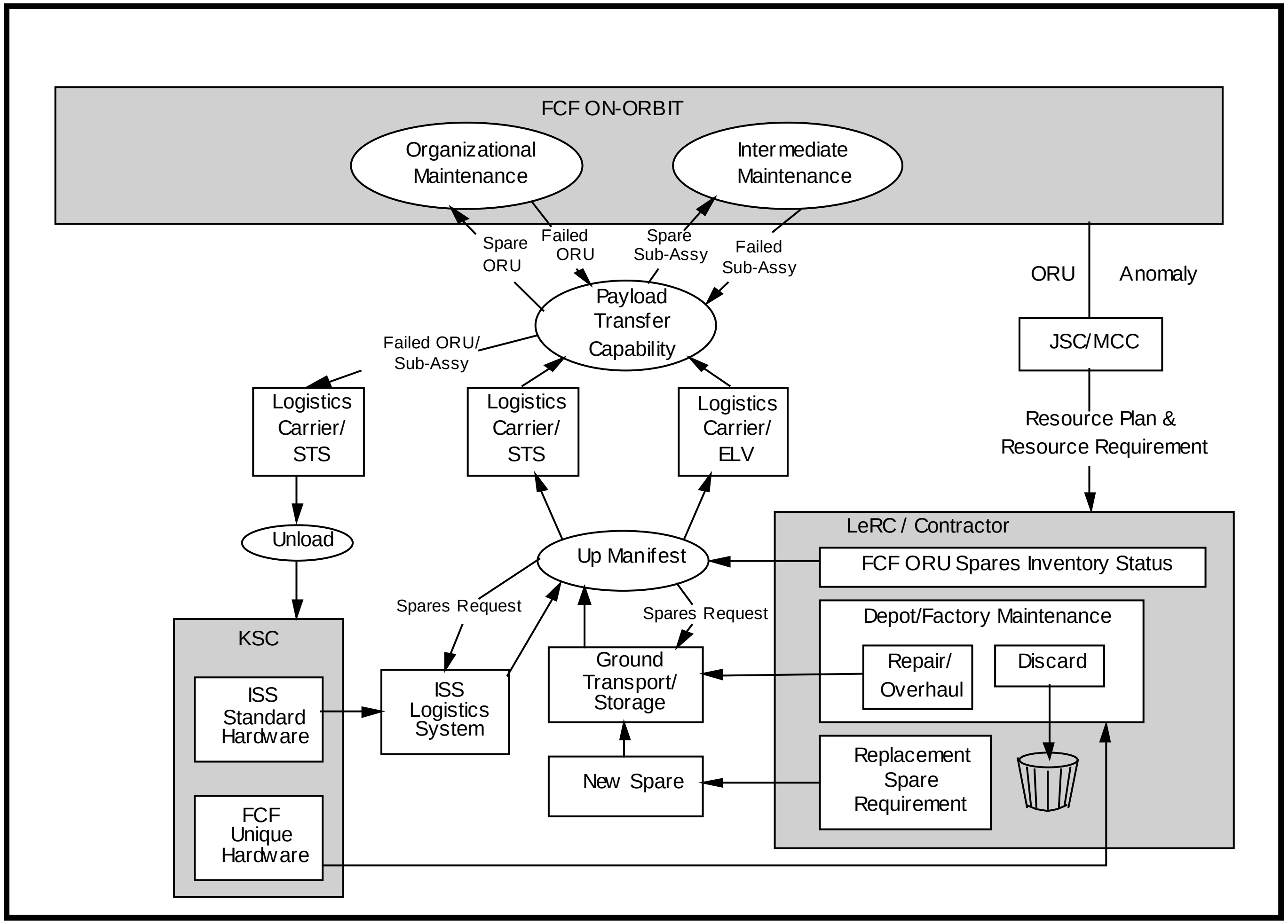
On-orbit intermediate maintenance is performed by crew members on FCF flight hardware removed from its' installed location. The major consideration in selecting on-orbit intermediate repair is whether upmass savings offset the expenditure of crew time to accomplish the repair.

Ground intermediate maintenance will be conducted at GRC. It will be limited to fault isolation, SRU and component replacement, minor refurbishment of operating mechanisms and hardware surfaces, replenishment of spent gases, some detail part replacement, and test, calibration, and recertification of hardware for flight.

Depot level maintenance at GRC and contractor facilities will include the repair, overhaul, remanufacture, refurbishment, test, calibration and recertification to return ORU or higher assemblies to flight-readiness.

The following page illustrates the Top Level Logistics and Maintenance Processes for the FCF.

FCF Logistics and Maintenance Concept



Chapter 9 – Operations

9 FCF FLIGHT OPERATIONS OVERVIEW

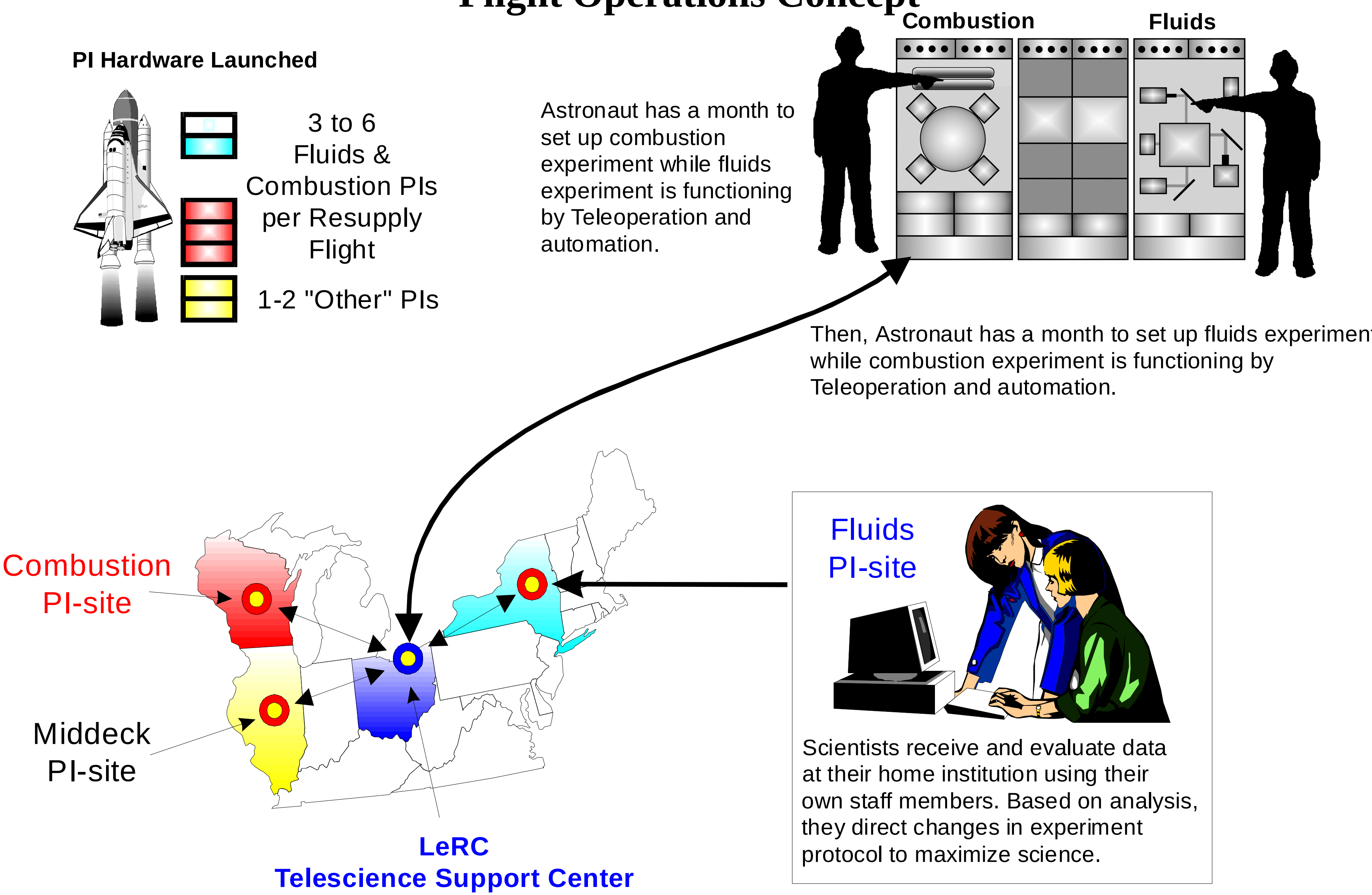
The FCF flight operations concept was driven by the need to conserve upmass and Astronaut crew time. Moreover, the on-orbit operations are conceived to maximize flexibility for the benefit of the Astronaut crew. The mission sequence given below is a highly simplified version, but it illustrates key points.

- Pre-Launch
  - Mission planning
  - Astronaut training, PI training
  - Mission simulations involving GRC and PI sites
- Launch
  - 3 to 6 PIs per resupply flight per year
  - 2 to 4 flights/year
  - Up mass per Fluids or Combustion PI in range of 25 to 75 kilograms based on realistic FCF upmass allocation
  - Up volume typically 0.055 cu-m per PI (2 cu-ft) to fit within limited on-orbit stowage
- On-orbit in ISS
  - Astronaut installs semi-autonomous experiment in shared rack which can run independently
  - Astronaut sets up Fluids experiment
  - Final adjustments to Fluids from GRC
  - While Fluids experiment runs (2-4 weeks of calendar time), Astronaut sets up Combustion experiment
  - Final adjustments to Combustion from GRC
  - While Combustion experiment runs, Astronaut removes old fluids experiment and installs new.
  - and so forth.
- On-earth at PI site and GRC (Telescience)
  - GRC operations staff operates Fluids, Combustion, and other science hardware remotely with very little Astronaut crew time required.
  - GRC archives data.
  - GRC operations staff manages interface actions with other NASA Centers and ISS.
  - PIs receive data at their sites per SRD
  - PI staffs analyze data, typically between data points.
  - PIs direct GRC operations staff to take actions which maximize scientific productivity.
- Post Flight
  - Additional data products to PIs per SRD
  - PIs publish reports

The following figure illustrates the flight operations concept.

FCF must accommodate 10 typical fluids/combustion PIs per year with a goal of accomodating 20. A key to accomplishing this is to keep Astronaut crew operations brief and at the crew's convenience.

Flight Operations Concept



9.1 On-orbit Operations

When a new set of FCF experiment or maintenance hardware arrives on-orbit, the crew will install the new hardware using the installation procedures, and will work with the FCF and PI teams to clarify any questions and resolve any anomalies.

Once the new hardware is installed, the crew using the laptop to ensure proper operation of the facility and the experiment hardware will perform verification tests. Once these tests are completed the FCF will be ready to conduct science.

From the remote site or the TSC the PI will work with the FCF operations team during experiment operations. Based on the short-term plan the FCF team will coordinate the initial power up of the facility with the POIC and the ISS crew. Once the FCF is powered, the FCF and PI teams will uplink the desired commands for the experiment. As the experiment proceeds the FCF and PI teams will monitor the video and data which is being downlinked, to ensure the experiment is proceeding as planned. If problems are encountered, the teams will work to resolve them. This may include enlisting the help of the POIC and the ISS crew, depending on the nature of the problem.

The FCF team will work with the POIC to ensure that the required data is being downlinked and distributed to both the TSC data system as well as the PI remote site.

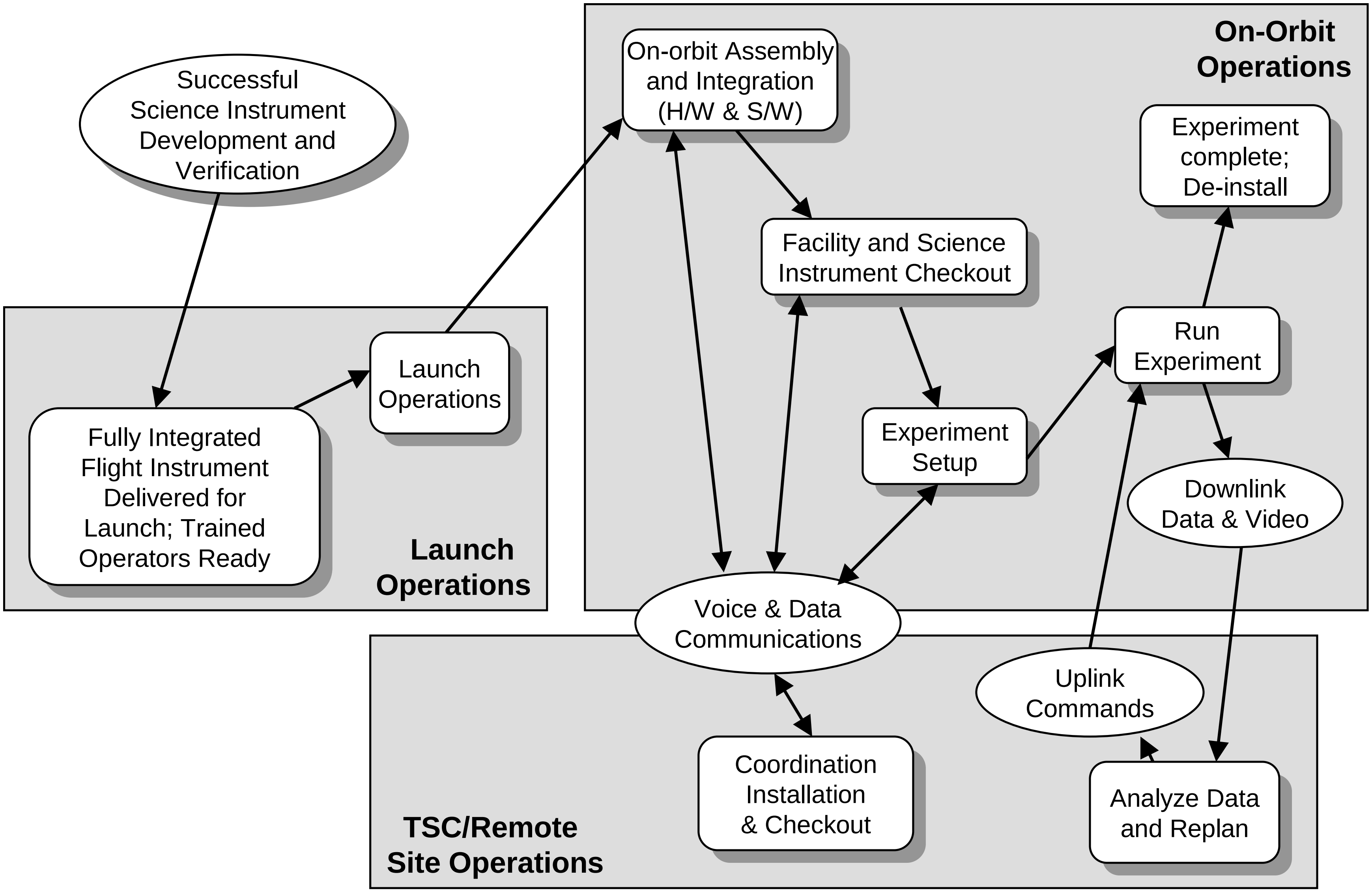
When an experiment run or series of test points have been completed and the PI has received the data, the FCF team will work with the crew to shut down the facility. It is anticipated that the PI will have at least a few days to review the data from an experiment or series of tests before the next set will be run. This allows the PI time make changes in the next set of experiments if desired.

When the experiment is complete, the experiment hardware will be removed from the FCF and put into the stowage lockers to be returned on the next logistics flight.

When not actively conducting science the FCF will be powered down and any scheduled maintenance will be performed based on crew availability.

The following page illustrates a top level view of the on - orbit operations of the FCF.

Flight Operations



9.2 Ground Operations

The FCF ground operations consist of all the activities required to support the on-orbit operation. These activities include coordination of on orbit procedure execution, real time procedure generation, command generation and uplink, communication with the POIC cadre and ISS crew, as well as science data monitoring and analysis.

The FCF operations team as well as the PI team will co-ordinate the performance of any procedures required for the setup and checkout of the FCF. This will be accomplished by monitoring air to ground communication as well as downlink video of crew activities.

Real time procedure generation takes place when an operation needs to be done by the crew and no procedure has been developed. In this case the ground operations team will consult with the engineering team and the POIC to develop the required procedure using the GIU as the development platform

The FCF operations team will generate all commands needed to operate the FCF on orbit system. They will incorporate all PI commands into one command string and will send the command string to the POIC for uplink. An alternative would be for the FCF to provide the command via voice communication to the crew for their input via the laptop. The FCF Ground Segment, in combination with the TSC, will include the necessary tools to generate the commands and to update the command database as required.

The most important ground operation will be monitoring the facility engineering and science data. This will be accomplished using TSC as well as FCF provided tools. The FCF team will monitor the engineering data to determine and track the health of the facility. They will also insure that the PI teams are receiving their data. All data will be stored for later analysis and distribution.

Mission planning during an increment will consist of updating the current short-term plan and onboard operations summary. This is done by submitting planning requests for the next week to the planning team at the POIC and participating in the weekly planning sessions to establish the execution priorities. All interactions with this team will be by video or teleconference and planning requests will be submitted through either PIMS or the Payload Planning system.

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9.3 Operational Scenarios

There are a variety of operational scenarios, which could be performed on any given increment. As noted in previous section, all operations performed on the FCF will have detailed procedures outlined step by step. What follows are brief descriptions of significant operations and activities, without the detailed step by step outline.

9.3.1 General Activities

New Hardware Installation

This includes the following types of new hardware:

- PI/Science Hardware
- FCF subsystem upgrades
- Maintenance Hardware

The operations involve first removing and stowing existing hardware, installing the new hardware and then testing and verifying proper operation of the new hardware. The FCF is currently being designed to minimize or eliminate the use of tools for experiment insertion and maintenance.

Software Maintenance/Upgrade

There are a number of different software loads, which will reside in the different avionics packages. They range from system software, which will require less frequent updates, to experiment procedures, which will be frequently updated. Typically new software loads will be uplinked through the ISS communication system to the FCF, where they will be verified and routed to the appropriate processor.

Experiment Operations

During experiment operations the PI will monitor the experiment progress. This will be done through the use of operational video. This is a compressed video stream which will allow the PI to monitor the experiment progress, but will likely not provide the resolution required for scientific analysis. Similar techniques have been used in Spacelab with very good results.

Anomaly Resolution

When unexpected problems are encountered in the FCF system, the FCF team attempts to diagnose the problem. Depending on the nature of the anomaly the team may use the Ground Integration Unit to determine the cause of the problem. This involves ensuring that the GIU is configured identically to the FCF flight unit and then trying to recreate the anomaly.

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Data Downlink

The FCF will send telemetry data over the 1553 bus, the Moderate Rate Link (MRL), the High Rate Link (HRL), and the station provided video system.

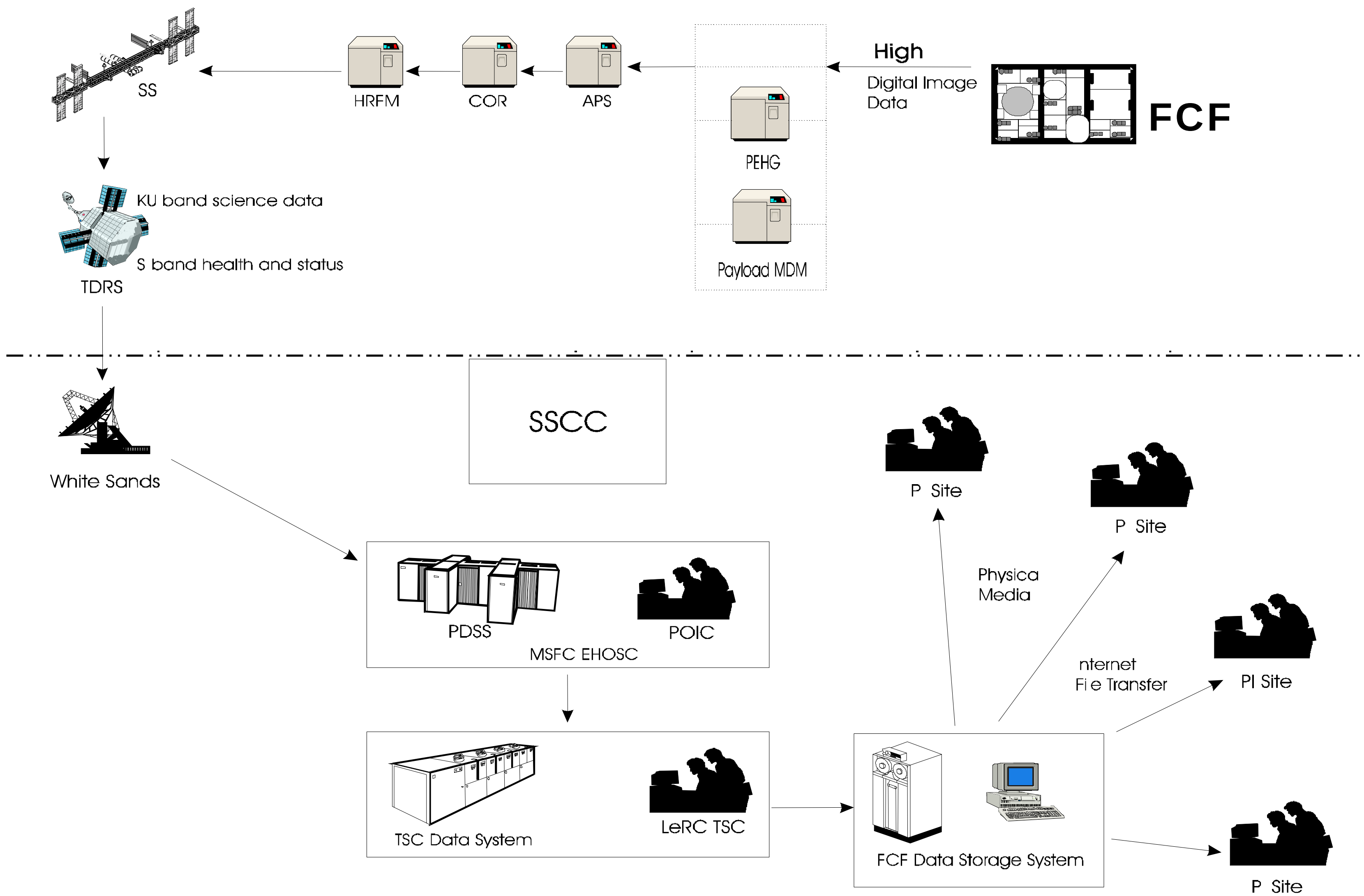
Once data has been generated it leaves the FCF via one of the specified interfaces. For the 1553 interface, low rate data will be sent to the payload MDM for transmission to the ground as well as for distribution to the ISS 1553 bus and caution and warning system. Once in the payload MDM the data gets sent to the Automated Payload Switch, which sends the data to the High Rate Frame Mux, which in turn transmits the data to the ground over TDRS. Once on the ground the data is distributed over NISN to the SSCC and the POIC for routing to the users as required.

Moderate rate data, which includes payload science data as well as facility data, will leave the FCF through the MRL interface. The data is sent over the ISS telemetry LAN through the PEHG to the APS and then on to the HRFM for transmission to the ground. Once on the ground the telemetry data is routed through the PDSS at MSFC, for any required processing, then on to the Remote sites and the TSC in TBD format.

High Rate data will be the high resolution and high frame rate data that will comprise most of the expected science return for the FCF. The high rate data will also require the most resources to provide. The data must be copied from the IPSUs to the IOP hard drive where it will wait until the command to downlink is received. Once the command is received the data will be written to the HRL interface at rates up to 100 Mbps. (Current ISS Ku-band availability limits the expected rate to no more than 20 Mbps) Once the data is written to the HRL interface it goes to the APS and on through the COR to the HRFM for transmission to the ground. This high rate data is not expected to be processed by the POIC/PDSS and will be sent directly to the PI site and the TSC for storage and analysis

The following page illustrates the High Rate Data downlink and distribution process for the FCF.

High Rate Data Downlink and Distribution



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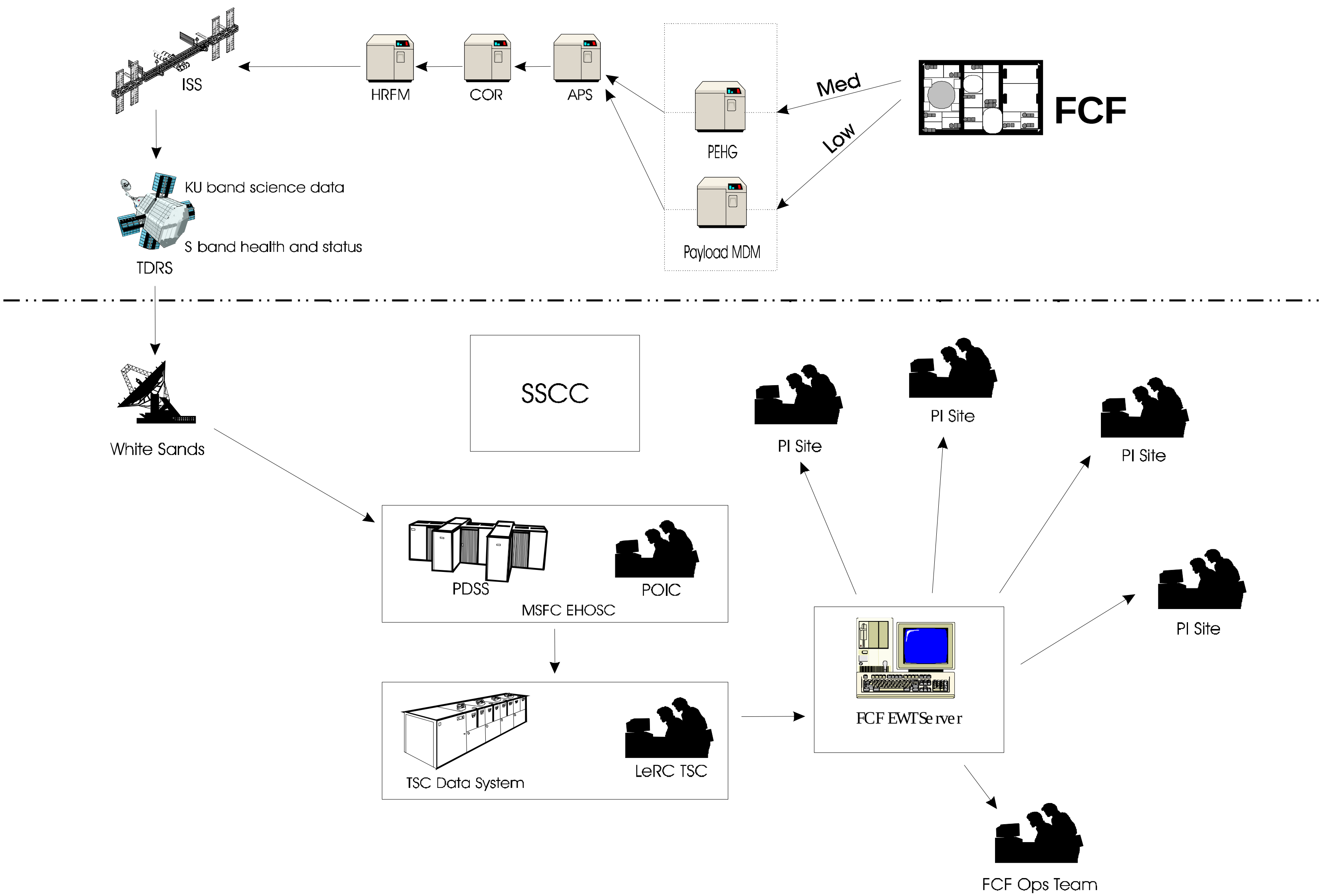
The following page illustrates the Low /Medium Data downlink and distribution process for the FCF.

Low / Medium Data Downlink and Distribution

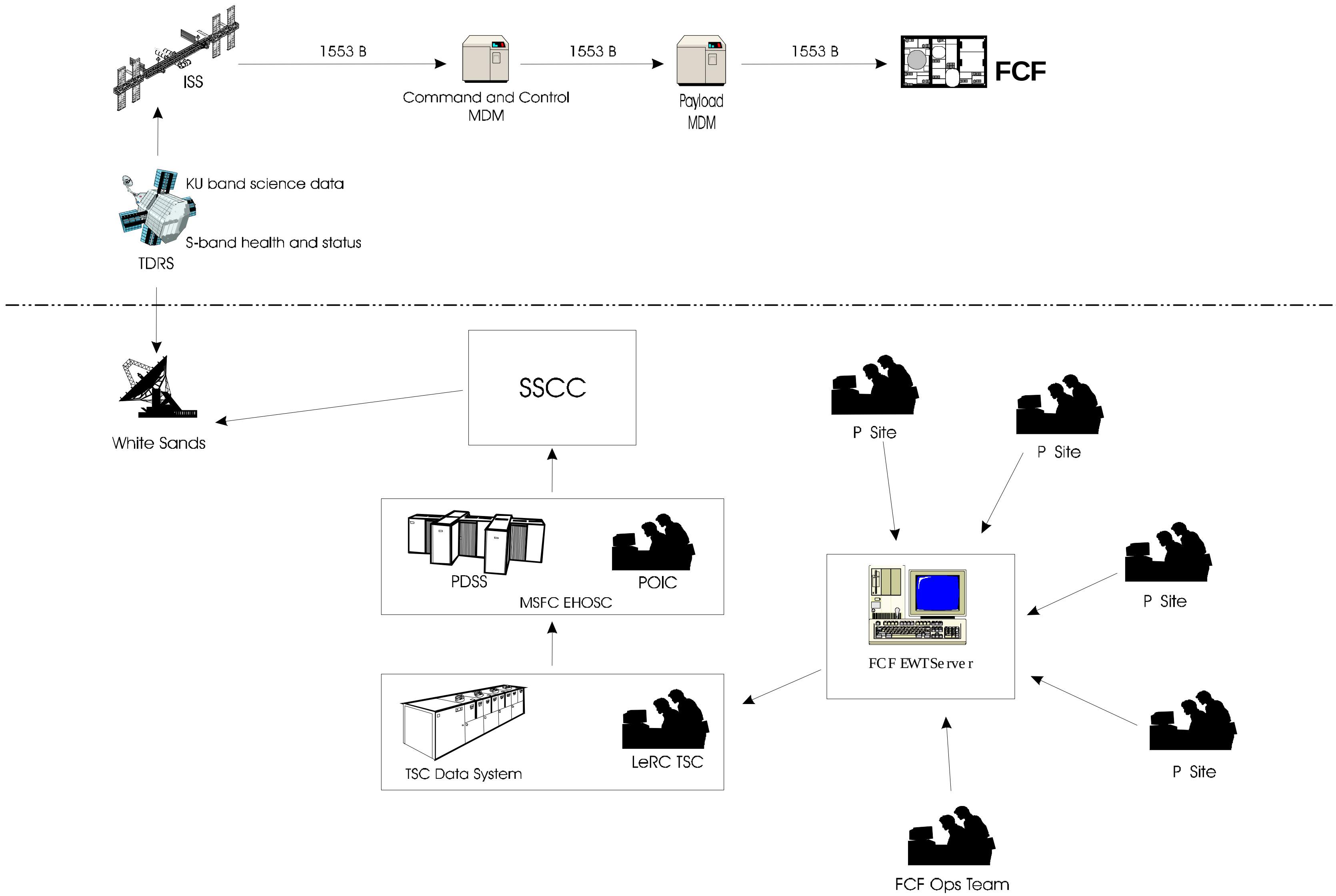


File Uplink

In order to communicate new test parameters and procedures, the PI at a remote site or the TSC will transmit a file to the TSC data system to be routed through the proper channels to the ISS. The TSC will transmit the file to the POIC where the file formatting will be validated along with source/destination headings. The file will be in formatted data packets, compatible with the ISS then forwarded to the SSCC for uplink routing to the ISS. The SSCC then sends the data to the NISN network. From the NISN network the file is sent to one of the TDRS. The TDRS transmits the data to the C&DH system on the ISS. The C&DH system then sends the file to the FCF through the following. The file arrives at the C&C MDM and is sent to the payload MDM. The Payload MDM then transmits the data to the FCF IOP via the 1553 network. The FCF IOP processes the file or sends it to the target processor.

The following page illustrates the File/Command Uplink path for the FCF.

File / Command Uplink



9.3.2 CIR Operations Scenarios

Several different types of operations will nominally be performed during the operations of the CIR before and after the SAR is deployed**.**

Front Panel Operations

There are several operations that take advantage of the ability to access equipment from the rack face requiring a minimum of tools and crew time. With the front panel open access is provided to the combustion chamber, gas bottles, EVP filters, and the IOP and EPCU.

EMS removal and installation

Each PI will require his own experiment mounting structure for supporting his equipment within the combustion chamber. The CIR allows this hardware to be changed out by simply opening the chamber (after verifying it is not pressurized) disconnecting the instrumentation and removing the EMS. A new experiment can be installed by simply inserting a new EMS into the chamber and reconnecting the instrumentation.

Chamber Window replacement

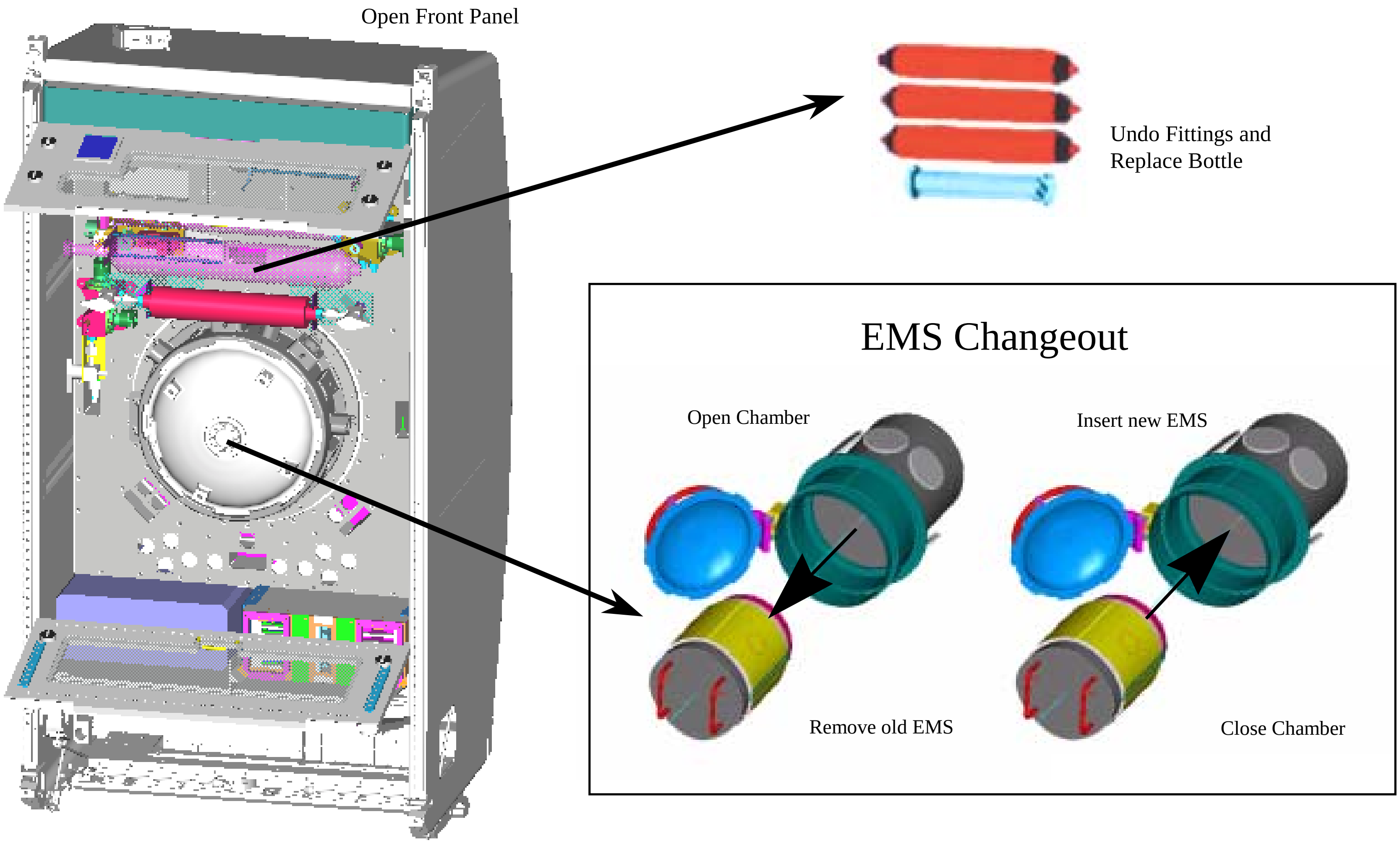
The combustion chamber allows up to 8 diagnostics to view the interior through special viewports. Over time it is expected that new windows with new optical properties will need to be installed in the chamber. This can be done with no special tools by removing the EMS, selecting the desired window and folding out the built in handle. The window can then be unscrewed from the chamber and replaced with a new one with the required properties.

Gas bottle installation and removal

Over the course of running multiple combustion experiments empty gas supply bottles will need to be removed and full ones installed. This will be a simple operation requiring only that the fittings on the bottle be removed, the bottle clamp be disengaged, and the bottle removed. The new bottle can then be installed.

The following page illustrates the available Front Panel Operations for CIR.

Front Panel Operations



IOP/EPCU Changeout

The Input/Output Processor as well as the Electrical Power Conversion Unit are self contained packages that use a simple mounting system to attach to the rack. They are design for easy removal for maintenance and replacement. The removal is accomplished by disconnecting all front interfaces, sliding out the package, disconnecting any rear mounted connections and removing the package from the rack.

Diagnostic configuration

Since the FCF will be utilized by a large number of investigators, the diagnostics will need to be changed on a regular basis. This can be accomplished with a minimum of tools and crew time due to the use of a common mounting plate in the CIR that provides easy access to and easy removal of diagnostic packages.

Experiment Execution

While it is not currently possible to describe all experiment executions, it is reasonable to assume that they will all follow the same general flow.

After any new equipment is installed and consumables replenished, the FCF team request power enabled at the CIR. The FCF team then sends the command to the IOP to power up the Combustion Element. This includes the necessary diagnostics, IPSUs and the FOMA.

Once the FCF team is satisfied that the Combustion element is operating properly, the PI can send the command to power up the experiment specific equipment.

When the PI and the FCF team are satisfied that the facility is operating properly, experiments can be performed.

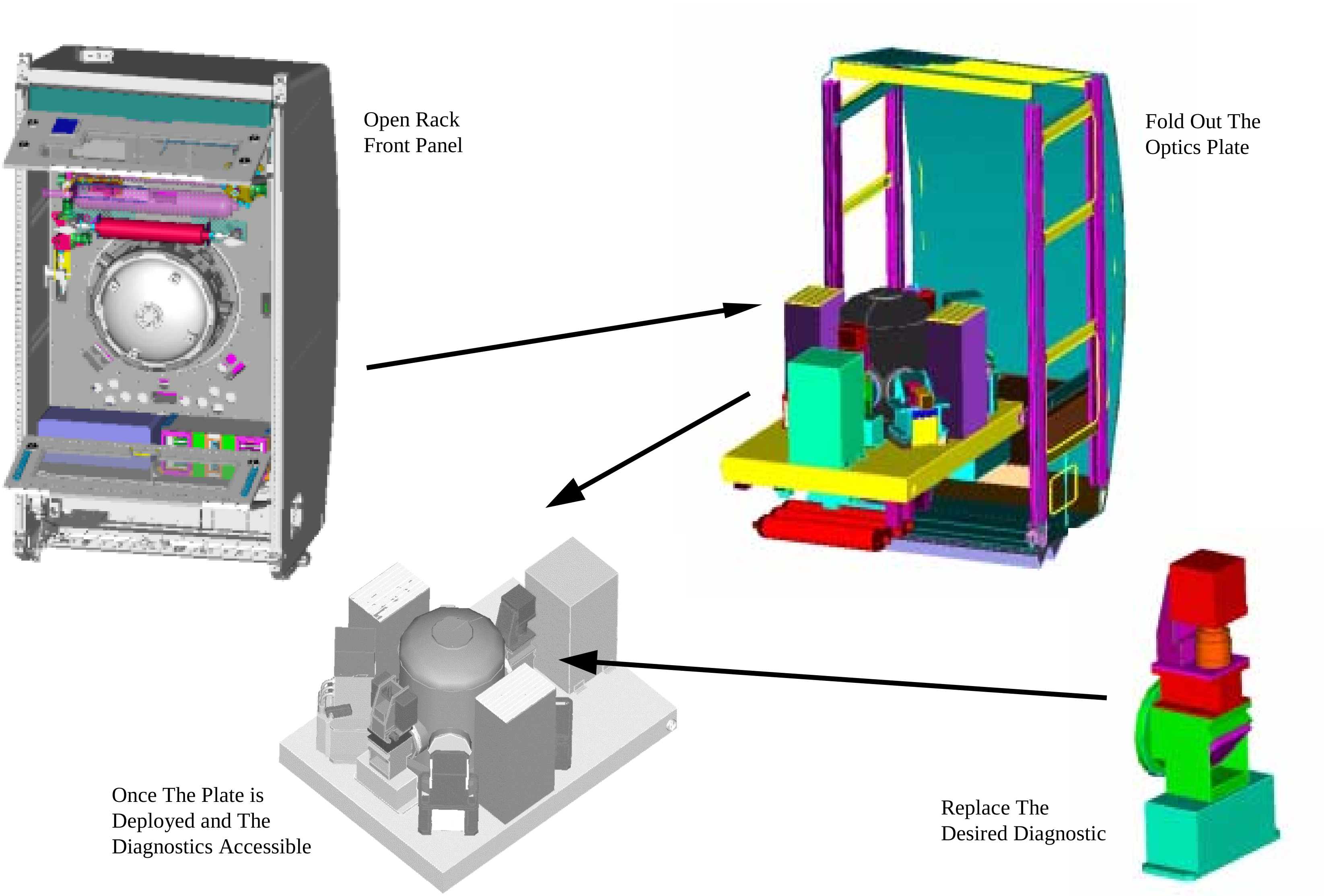
Conduct test matrix.

Experiment will run until current matrix is complete or is instructed to terminate for any reason. Operational data will be downlinked to observe experiment status. Science data will be downlinked to the extent possible during the experiment and will be stored until data can be downlinked. *If data from one test point is required to be analyzed prior to the next test point then the facility will be placed in downlink or low power mode while the data is downlinked and analyzed.*

After the last test in the current matrix, the facility can be shut down or reconfigured for a new experiment run.

The following page illustrates a Diagnostic Changeout / Reconfiguration for CIR.

Diagnostic Changeout/Reconfiguration



9.3.3 FIR Operations Concepts

As with the CIR the FIR will operate as an integrated rack until the SAR is deployed. A number of typical operations scenarios for FIR are described below.

Experiment and installation;

Each PI will require his own experiment mounting structure for supporting his equipment within the combustion chamber. The FIR allows this hardware to be changed out by simply opening the front panel disconnecting the instrumentation and removing the old experiment. A new experiment can be installed by simply inserting a new hardware element into the FIR and reconnecting the instrumentation.

IOP/EPCU Changout

The Input/Output Processor as well as the Electrical Power Conversion Unit are self contained packages that use a simple mounting system to attach to the rack. They are design for easy removal for maintenance and replacement. The removal is accomplished by disconnecting all front interfaces, sliding out the package, disconnecting any rear mounted connections and removing the package from the rack.

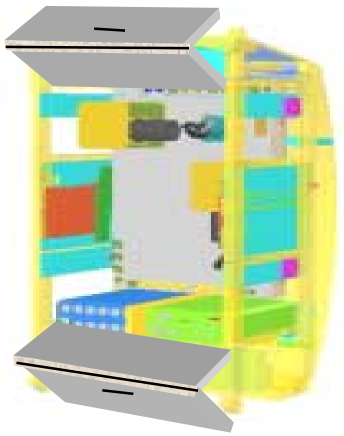
Diagnostic and Electronics configuration

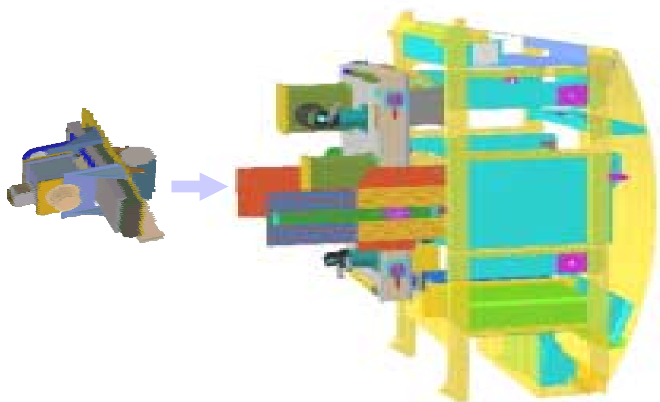
Since the FIR will be utilized by a large number of investigators, both the electronics and the diagnostics will need to be changed or reconfigured on a regular basis. This can be accomplished with a minimum of tools and crew time due to the use of a common mounting plate in the FIR that provides easy access to and easy removal of diagnostic packages.

In order to change out the diagnostics or reconfigure the electronics it will first be necessary to open the front panel of the FIR and translate the optics plate out of the rack. The plate can then be rotated perpendicular to the rack and locked in place. Once deployed the desired equipment can be reconfigured or replaced. Once the diagnostics and electronics have been reconfigured as desired, the plate can be returned to the rack and checkout can begin using calibration equipment

The following page illustrates an Experiment Installation Setup and Diagnostic/Electronic package installation for FIR.

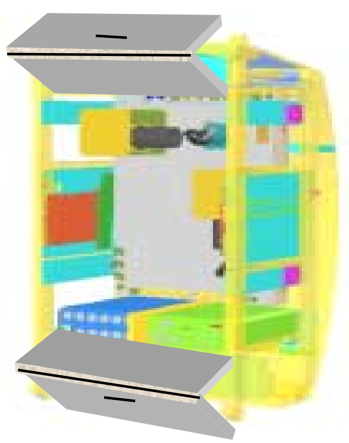
Experiment Installation Setup

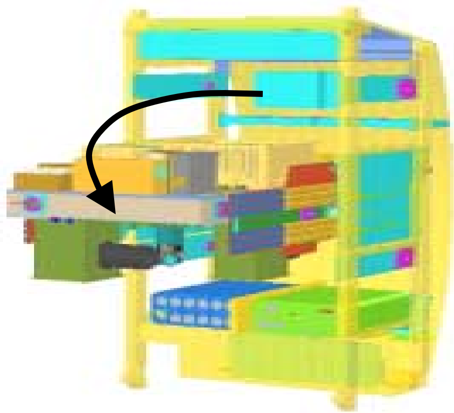

Open Doors

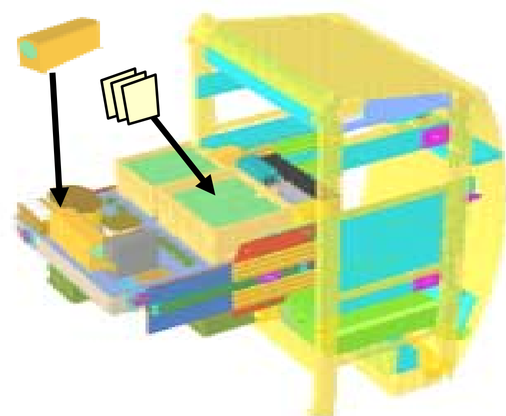

Install Experiment Hardware


Connect Interfaces and
Align Diagnostics

Diagnostic and Electronic Installation


Open Doors


Fold Down Optics Bench


Install Diagnostics and Electronics

Experiment Execution

While it is not currently possible to describe all experiment executions, it is reasonable to assume that they will all follow the same general flow.

Prior to an experiment run the FIR will be reconfigured and any new equipment installed.

After the FIR is powered up the FCF team then sends the command to the IOP to power up the rest of the FIR element. This includes the necessary diagnostics, IPSUs, etc.

Once the FCF team is satisfied that the FIR is operating properly, the PI can send the command to power up the experiment specific equipment.

When the PI and the FCF team are satisfied that the facility is operating properly, experiments can be performed.

Conduct test matrix.

Experiment will run until current matrix is complete or is instructed to terminate for any reason. Operational data will be downlinked to observe experiment status. Science data will be downlinked to the extent possible during the experiment and will be stored until data can be downlinked. *If data from one test point is required to be analyzed prior to the next test point then the facility will be placed in downlink or low power mode while the data is downlinked and analyzed.*

After the last test in the current matrix, the facility can be shut down or reconfigured for a new experiment run.

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9.3.4 SAR Operations

When the Shared Accommodations Rack is deployed it will provide the CDMS and data processing services that are required for the CIR and the FIR to conduct science. The principle difference this will make in the operations of the FCF will be the following.

SAR Rack will be required to power up before the specific science rack. This is required because the SAR provides the command and data interfaces between the FCF and the ISS.

In addition all data will be recorded in the SAR in order to be processed before downlinking to the TSC.

The principle addition to the crew activities required for the FCF operations involving the SAR is that the crew will be required to make and break all connections between the SAR and the science racks. This will be done on an as needed basis.

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9.4 Training

Training will be provided to the crew and the ground support personnel in order to insure the success of the FCF science operations. Each group will be trained separately to insure a fundamental understanding of the tasks required of them. When this is completed the crew and GSP will undergo integrated training in conjunction with the SSCC and POIC to certify that all personnel and systems are ready for operations.

9.4.1 Crew Training

The objectives for crew training will be to provide them with a fundamental understanding of the science objectives and operations of the FCF as well as to insure proficiency in all required operations and maintenance tasks required of the increment crew.

9.4.1.1 Approach

The basic science and operations training will be conducted using classroom presentations, Computer Based Training (CBT) modules, training videos, and will provide a complete overview of the FCF science, components, system interfaces, operations, and logistics.

Hands-on training using the FCF simulator and part task trainers will be conducted to allow the crew to observe and perform the nominal, malfunction, and maintenance procedures which they will be required to perform.

After the basic familiarization training and hands on instruction the crew will participate in several levels of simulations in order to reinforce the FCF training. These simulations will progress from payload only simulations where the crew will review the nominal FCF operations to integrated payload complement and multisegment simulations which will train the crew on the specific increment configuration stressing ISS systems training using the integrated timeline and procedures.

On orbit training will be used when the crew is required to perform an activity for which they have not been trained, the FCF operations team will work in conjunction with the TSC at GRC, the Payload Operations and Integration Center (POIC) at MSFC, the Space Station Control Center (SSCC) at JSC , and crew members aboard the ISS in order to provide training materials prior to the operation being executed.

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9.4.1.2 Support

Several different organizations and facilities will support the FCF training activities.

The Payload Training Center (PTC), located at Johnson Space Center, will support payload operations training, integrated ISS training, integrated simulations of payload operations, and any required payload proficiency training.

FCF training at the PTC will be accomplished using the FCF PTS (Payload Training Simulator), which will be a high fidelity representation of the FCF providing flight like crew interfaces and hardware.

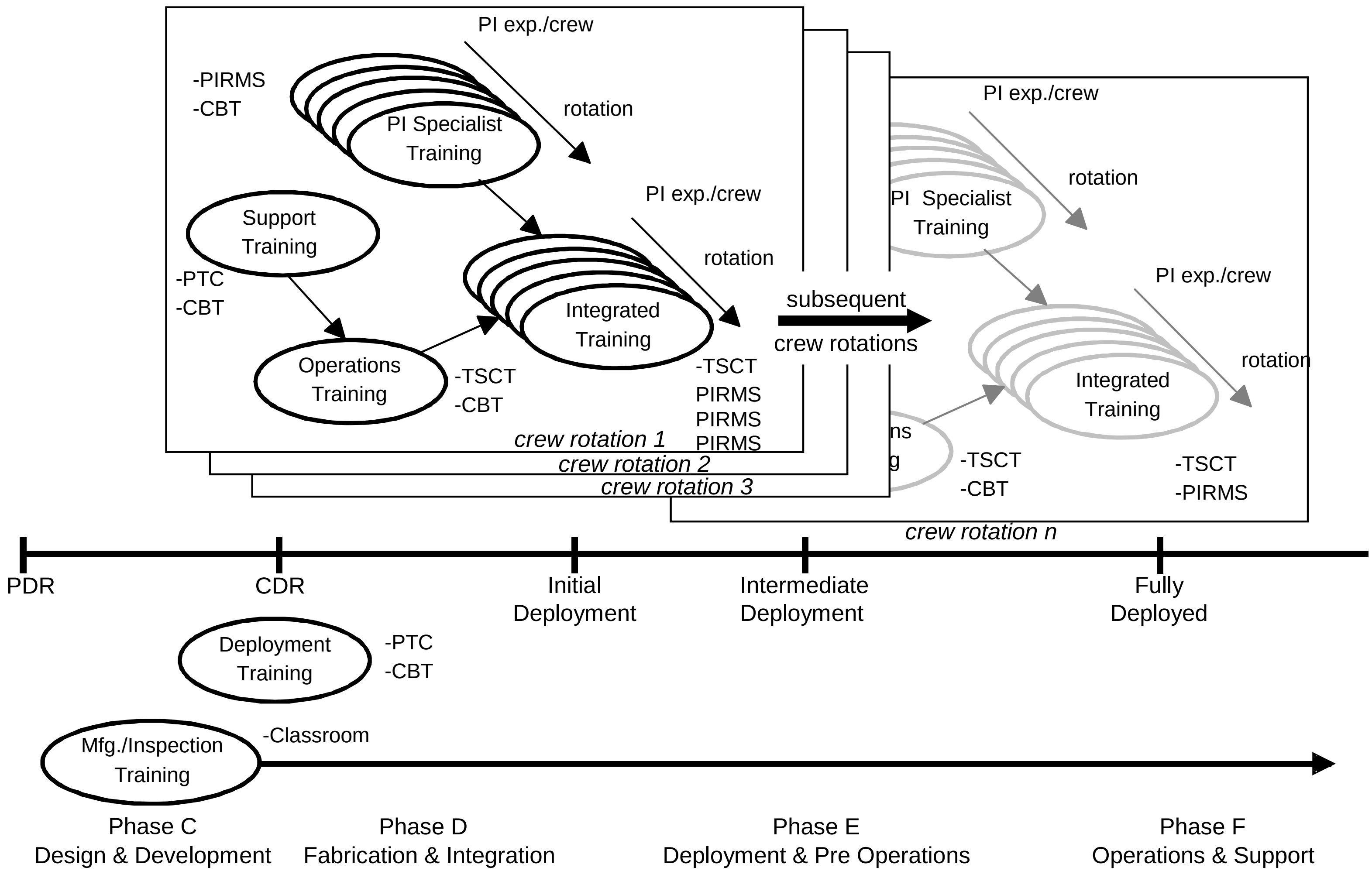
Training objectives and simulator requirements will be developed during the Training Strategy Team process coordinated by MSFC and documented in the payload training dataset as well as the training lesson plans.

The GRC will support crew training during the integrated simulations. The TSC will allow the FCF operations team as well as the PI teams to work in conjunction with the crew to reinforce the FCF specific training.

On orbit training will be developed by ground personnel utilizing the GIU at GRC and could be delivered by computer based training as well as voice and video communication with the crew

The following figure illustrates the training philosophy of multiple increment training for the FCF.

Training


PI exp./crew
-PIRMS
-CBT
rotation
PI Specialist Training
PI exp./crew
Support Training
rotation
-PTC
-CBT
Integrated Training
subsequent crew rotations
Operations Training
-TSCT
-CBT
-TSCT
PIRMS
PIRMS
PIRMS
crew rotation 1
crew rotation 2
crew rotation 3
PI exp./crew
rotation
PI Specialist Training
PI exp./crew
rotation
Integrated Training
-TSCT
-CBT
-TSCT
-PIRMS
crew rotation n
PDR
CDR
Initial Deployment
Intermediate Deployment
Fully Deployed
Deployment Training
-PTC
-CBT
Mfg./Inspection Training
-Classroom
Phase C
Design & Development
Phase D
Fabrication & Integration
Phase E
Deployment & Pre Operations
Phase F
Operations & Support

Chapter 10 - Acronyms

List of Acronyms

A	Amp
AC	Assembly Complete
A/D	Analog-to-Digital
AFC	Auxiliary Fluids Container
APD	Avalanche Photo Diode
APT	Automated Position and Tracking
APTF	Automatic Positioning Tracking Focusing
APS	Automated Payload Switch
ARIS	Active Rack Isolation Subsystem
ATCS	Air Thermal Control System
ATCU	Air Thermal Control Unit
Atm, atm	Atmosphere
AWG	American Wire Gauge
B & W, b & w	Black and White
B/L	Baseline
BB	Breadboard/Brassboard
BCD	Baseline Control Document
BDPU	Bubble/Droplet Particle Unit
BSD	Baseline System Description
C	Celsius
C&C	Command and Control
C&DH	Command and Data Handling
C&T	Communications and Tracking
C&W	Caution and Warning
CAN	Controller Area Network
CCD	Charged Coupled Devices
CCSDS	Consultative Committee for Space Data Systems
CDIP	Command and Data Interface Package
CDMS	Command and Data Management System
CDR	Concept Design Review
CFCF	Commercial Fluids/Combustion Facility
CFM, cfm	Cubic Feet per Minute
CIR	Combustion Integrated Rack
Cm, cm	Centimeter
CM	Combustion Module (in reference to Combustion Module-I)
CM	Compliance Matrix
CO2, CO_2	Carbon Dioxide
CoFR	Certificate of Flight Readiness
COI	Computer Optics Incorporated
CORBA	Common Object Request Broker Architecture
COTS	Commercial Off-the-Shelf
CP	Chamber Package
cPCI	Compact Peripheral Component Interconnect
CPU	Central Processing Unit
CSC	Computer software Components
CSCI	Computer Science Configuration Item
CTB	Central Thermal Bus
CVIT	Common Video Interface Transmitter
CVB	Constrained Vapor Bubble
CWRU	Case Western Reserve University
D/A	Digital-to-Analog
DAC	Digital-to-Analog Converter

List of Acronyms

DC	Direct-Current
DC/DC	Direct-Current-to-Direct-Current
DCE	Droplet Combustion Experiment
DCM	Diagnostics Control Module
DDCU	Direct-Current-to-Direct-Current Converter Unit
DDT&E	Design, Development, Test, and Evaluation
DFA	Door Fan Assembly
DIA, dia	Diameter
DIC	Differential Interference Contrast
DIO	Digital I/O
DLS	Dynamic Light Scattering
DOF	Degrees of Freedon
DSP	Digital Signal Processing
DWS	Diffusing Wave Spectroscopy
EA	Experiment Assembly
ECLSS	Environmental Control and Life Support System
ECS	Environmental Control Subsystem
ECW	Emergency Caution and Warning
EDAC	Error Detection and Correction
EEE	Electrical, Electronic, and Electromechanical
EM	Engineering Model
EMC	Electro-Magnetic Compatibility
EMF	Electromotive Force (volts)
EMI	Electro-magnetic Interference
EP	Experiment Package
EPCU	Electrical Power Control Unit
EPS	Electrical Power Subsystem
ER	Express Rack
ESA	European Space Agency
ESP	Electronic Support Package
ESSA	EPCU Shutoff Switch Assembly
ETM	Equipment Transfer Module
EVP	Exhaust Vent Package
EWT	Embedded Web Technology
Exp.	Experiment
F	Fahrenheit
FC	Fiber Connector
FC/PM	Fiber Connector/Polarization Maintaining
FCF	Fluids and Combustion Facility
FCU	FOMA Control Unit
FDDI	Fiberoptic Data Distributed Interface
FDSS	Fire Detection and Suppression System
FEA	Fluids Experiment Assembly
FIR	Fluids Integrated Rack
FO	Fiber Optic
FOMA	Fuel/Oxidizer Management Assembly
FOV	Field of View
FPS, Fps, fps	Frames per Second
FPA	Focal Plane Assembly
FRBP	Fluids Rotating Bench Package
FRPC	Flexible Remote Power Controller
FRPCA	Flexible Remote Power Controller Assembly
FRPCM	Flexible Remote Power Controller Module
FSAP	Fluid Science Avionics Package
GB, Gb	Gigabyte
GC	Gas Chromatograph

List of Acronyms

GDP	Gas Delivery Package
GFCI	Ground Fault Circuit Interrupt
GFE	Government-furnished Equipment
GIP	Gas Interface Panel
GIS	Gas Interface System
GIU	Ground Integration Unit
GN2, GN_2	Gaseous Nitrogen
GPI	Generic Package Interface
GPVP	Generic Payload Verification Plan
GRC	Glenn Research Center
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
GUI	Graphical User Interface
H/W	Hardware
HCR	Hardware Concept Review
HEDS	Human Exploration and Development of Space
HFR	High Frame-rate
HiBM	High Bit Depth/Multispectral
HR	High Resolution
HR, Hr, hr	Hour
HRDL	High-rate Data Link (Fiber Optic)
HRFM	High-rate Frame Multiplexer
HRL	Horizontal Reference Line
HS	Health and Status
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
HWCI	Hardware Configuration Item
Hz	Hertz
I/F	Interface
I/O	Input/Output
IAM	Image Acquisition Module
ICA	Interface Control Annex
ICD	Interface Control Document
IDGE	Isothermal Dendritic Growth Experiment
IDL	Interface Definition Language
IEEE	Institute of Electrical and Electronics Engineers
IOP	Input/Output Processor
IPP	Image Processing Package
IPSU	Image Processing and Storage Unit
IPT	Integrated Project Team
IRD	Interface Requirements Document
IRR	Interface Resource Ring
ISA	Industry Standard Architecture
ISCAN	pp 85- FIR
ISPR	International Standard Payload Rack
ISS	International Space Station
ISSP	International Space Station Program
ITCS	Internal Thermal Control System
IVA	Intravehicular Activity
JSC	Johnson Space Center
KG, Kg, kg	Kilogram
KHz, kHz	KiloHertz
kPa	Kilo Pascal
KSC	Kennedy Space Center

List of Acronyms

KU	pp 225 - FIR
KW, kw	Kilowatt
Lab, lab	Laboratory
LAN	Local Area Network
Lb(s), lb(s)	Pound(s)
PU	Panel Unit
Lbm	Pounds-mass
LCDT	Limit Check Definition Table
LED	Light Emitting Diode
LLL	Low-light Level
LMM	Light Microscopy Module
LOS	Loss of Signal
LRDL	Low-rate Data Link
LSA	Logistics Support Analysis
LT	Low Temperature
M	Million
Max	Maximum
MDCA	Multi-user Droplet Combustion Apparatus
MDM	Multiplexer/Demultiplexer
MDP	Maximum Design Pressure
MFC	Mass Flow Controller
MGBX	Middeck Glove Box
MGFA	Multi-use Gaseous Fuel Apparatus
MIUL	Materials Identification and Usage list
Mm, mm	Millimeter
MPEG	Motion Picture Experts Group
MPLM	Multi-purpose Logistics Module
Mrad, mrad	Milliradians
MRDL	Medium Rate Data Link (Ethernet)
MRL	Medium Rate Link
MRP	Microgravity Research Program
MRPO	Microgravity Research Program Office
MSAD	Microgravity Science and Applications Division
MSD	Microgravity Sciences Division
MSFA	Multi-use Solid Fuel Apparatus
MSFC	Marshall Space Center
MSG	Microgravity Science Glovebox
MT	Moderate Temperature
MTA	Maintenance Task Analysis
MTBF	Mean Time between Failure
MTF	Modulation Transfer Function
MTL	Moderate Temperature Loop
MUA	Material Usage Agreement
MUIL	Materials Identification and Usage List
mW	MilliWatt
MWA	Maintenance Work Area
N/A, n/a	Not Applicable
NASA	National Aeronautics and Space Administration
NHB	NASA Handbook
Nm, nm	Nanometer
NSTS	National Space Transportation System
NTSC	National Television Standards Committee
OM	Optics Module
OMG	Object Management Group

List of Acronyms

OPI	Optics Plate Interface
OPS, Ops	Operations
ORU	Operational/Orbital/Online Replacement Unit
OZ2	ISS PO Mission Integration and Planning
OZ3	ISS PO Hardware and Software Engineering Integration
P/L	Payload
PAL	Phase Alternating Line
PBE	Pool Boiling Experiment
PCI	Peripheral Component Interconnect
PCS	Physics of Colloids in Space
PCS	Portable Computer System
PDC	Payload Development Center
PDR	Preliminary Design Review
PEP	Payload Executive Processor
PFE	Portable Fire Extinguisher
PFFL	Prime Fixed Focal Length
PFM	Pulse Frequency Modulation
PHaSE	Physics of Hard Spheres
PI	Principal Investigator
PIA	Payload Integration Agreement
PI-FSAP	Principal Investigator – Fluids Science Avionics Package
PIM	Payload Integration Manager
PIV	Particle Image Velocimetry
PMC, PMC+	PCI Mezzanine Card
PMT	Photo Multiplier Tube
PO	Payloads Office/Project Office
POIC	Payload Operations Integration Center
Ppr, ppr	Pulses per revolution
Psi, psi	Pounds per square inch
Psia, psia	Pounds per square inch absolute
PSR	Pre-ship Review
PSRP	Payload Safety Review Panel
PTC	Payload Training Center
PVP	Payload Verification Plan
QC	Quick-connect
QD	Quick-disconnect
Qual	Qualification
RAID	Redundant Arrays of Inexpensive Disks
RAM	Random Access Memory
RDR	Requirements Definition Review
REU	Remote Electronic Unit
RFCA	Rack Flow Control Assembly
RFCVA	Rack Flow Control Valve Assembly
RHA	Rack Handling Adapter
RIP	Rack Interface Panel
RMSA	Rack Maintenance Switch Assembly
RPC	Remote Power Controller
RPCM	Remote Power Controller Module
RTD	Resistive Temperature Device
RTRU	Rack-to-Rack Umbilical
RUP	Rack Utility Panel
S/W	Software
SAMS	Space Acceleration and Measurement System

List of Acronyms

SAR	Shared Accommodations Rack
SBC	Single-board Computer
SCADA	Supervisory Control and Data Acquisition
SCFM	Standard Cubic Feet per Minute
SCSI	Small Computer Systems Interconnect
SD	Science Diagnostics
SD	Smoke Detector
SDADN	Science Data Acquisition and Distribution Network
SDL	Serial Data Link
SDP	Safety Data Package
SDRAM	Synchronous Dynamic RAM
Sec, sec	Second
SEE	Single Event Effect
SHARC	Super Harvard Architecture Computer
SLM	Standard Liters per Minute
SLS	Static Light Scattering
SMAC	Spacecraft Maximum Allowable Concentration
SMD	Silicon Mountain Device
SPDA	Secondary Power Distribution Assembly
SPOE	Standard Payload Outfitting Equipment
SRD	Science Requirement Document
SRED	Science Requirements Envelope Document
SSC	Station Support Computer
STD, std	Standard
STDCE	Surface Tension Driven Convection Experiment
STS	Space Transportation System
TBD	To be Determined
TBR	To be Resolved
TDRSS	Technical Data Relay Satellite System
TE	Thermoelectric
TEC	Thermal Electric Cooler
TPI	Threads per inch
TREK, TRek	Telescience Resource Kit
TSC	Telescience Support Center
TTL	Transistor-Transistor Logic
UF	Utilization Flight
UHFR	Ultra-high Frame-rate
UIP	Utility Interface Panel
UML	Unified Modeling Language
UML	Universal Mounting Location
UOP	Utility Outlet Panel
US, U.S.	United States
US Lab	United States Laboratory Module
USRA	Universities Space Research Association
VAC, vac	Vacuum
VDC, Vdc	Volts Direct Current
VES	Vacuum Exhaust System
VME	Versa Module Eurocard bus
VRS	Vacuum Resource Service
VVS	Vacuum Vent System
W	Watt
WA	Work Area
WDM	Wave Division Multiplexing

List of Acronyms

USRA	Universities Space Research Association
VAC, vac	Vacuum
VDC, Vdc	Volts Direct Current
VES	Vacuum Exhaust System
VME	Versa Module Eurocard bus
VRS	Vacuum Resource Service
VVS	Vacuum Vent System
W	Watt
WA	Work Area
WDM	Wave Division Multiplexing
WFCA	Water Flow Control Assembly
WGS	Waste Gas System
WIP	Water Interface Panel
WTCS	Water Thermal Control System
Yr	Year

Appendix A Combustion Integrated Rack (CIR)

Table of Contents

Section A.1 Combustion Integrated Rack (CIR) Overview

A.1 Combustion Integrated Rack Overview

The CIR is a stand-alone facility for conducting combustion experiments during the early stages of ISS assembly and operation. Its capabilities as a support facility are defined by the performance envelopes described in the FCF Science Requirements Envelope Document (FCF-DOC-002) and by applicable ISS-provided support capabilities. Its capabilities as an experiment-specific, integrated experiment facility are (typically) defined by applicable, individual experiment science requirements documents.

The concept described in Section 4 of this document provides all systems required to implement the mechanical, electrical, and data management and control aspects of a facility addressing both the breadth of the requirements and the constraints of external supporting systems. Selected diagnostic and measurement systems are identified which are capable of meeting the initial complement of flight experiments while defining the long-term concepts for modular, multi-user experiment hardware

A.1.1 PURPOSE OF THE CIR

The purpose of the CIR is to:

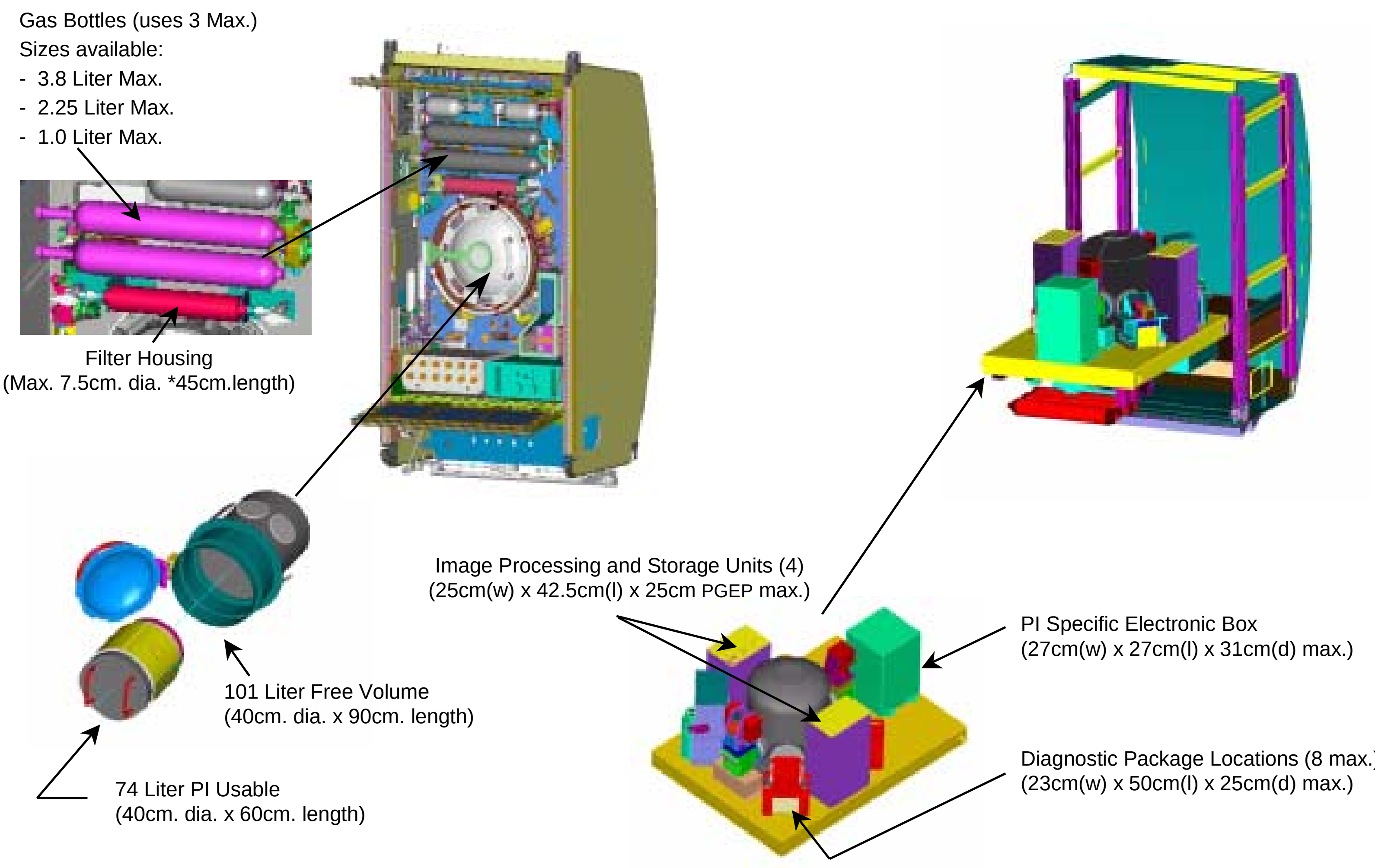
1. Provide early access to ISS for the Combustion Science discipline program as a stand-alone facility which can accommodate selected flight experiments;
2. Provide essential infrastructure and capabilities for the combustion element of the integrated FCF which will meet all requirements for the combustion science discipline program; and
3. Provide a logical and cost-effective precursor to the FCF through:

- Definition of common hardware elements (i.e., interchangeable with the Fluids Integrated Rack (FIR) and the Shared Accommodations Rack (SAR));
- Clear definition of common interfaces;
- Development of hardware and operational concepts requiring minimal crew interaction;
- Development of efficient concepts for hardware development and integration; and
- Science operation of experiments.

The following figure depicts elements of the FCF CIR hardware concept.

Figure 2-1

Elements of CIR Hardware Concept



A.1.2 CONCEPT OF THE CIR

The concept of the CIR is to provide a cost-effective approach and a long-lived answer to challenging requirements and significant constraints. To accomplish this, the CIR utilizes:

- ISS-provided common hardware to minimize costs when the capabilities are compatible with the science mission;
- FCF-generated common hardware architecture (including interface design) and subsystems, when possible, to minimize cost and increase redundancy;
- Accessible, modular assembly when possible to optimize access for flexible reconfiguration and maintenance while minimizing impact on crew time;
- Modular, upgradable hardware and software concepts permitting evolutionary implementation of capabilities to meet selected requirements or improvements;
- When possible, FCF-generated diagnostic and measurement subsystems chosen to optimize the long-term benefits to the science program;
- Designs and operational concepts which maximize accessibility and flexibility for users implementing experiment-specific capabilities while minimizing requirements for up- and down-mass;
- Designs and operational concepts that optimize the implementation and operation of safety-related systems and documentation.

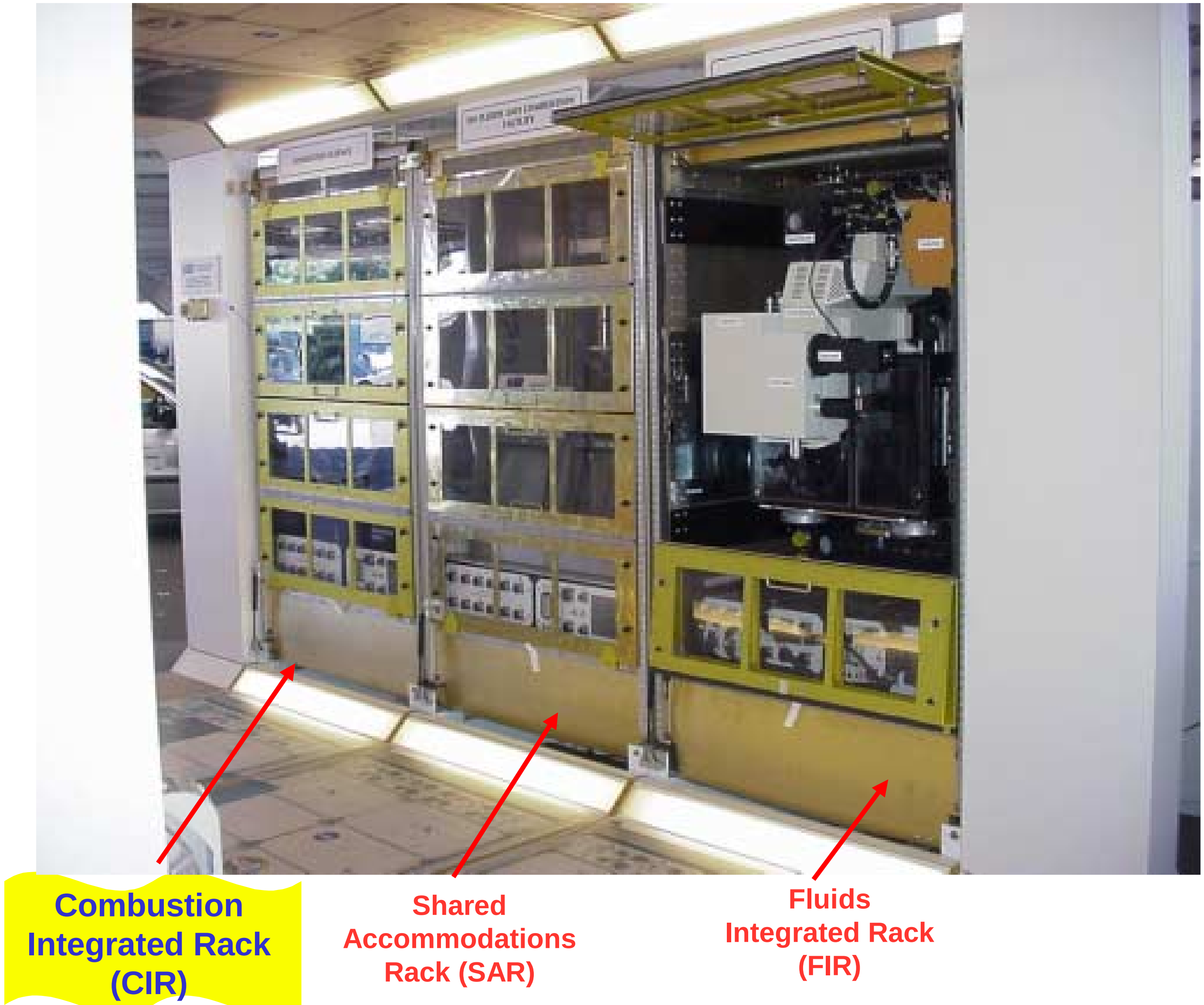
A.1.3 OPERATIONAL CONCEPT FOR CIR

The operational concept for CIR is to allow ISS crew members to easily install Principal Investigator (PI) hardware into the CIR and prepare the CIR for operation, and then allow the PI testing to be performed and monitored from the ground. To provide this capability, the CIR:

- Provides easy and straightforward set up of PI specific hardware;
- Allows crew members to adjust and reposition components (as appropriate) without special tools or equipment;
- Ensures that installation and replacement of PI equipment and CIR components results in safe, reliable CIR operation;
- Permits execution of system self-tests and leak tests from either ground operators or the crew;
- Permits PI hardware test initiation and data gathering from the ground operators;
- Permits test shutdown by ground operators.

Since the CIR must accommodate a wide variety of experiments requiring various types of measurement techniques and other unique factors, the design features the capability to remove, replace or upgrade different experiment packages within the chamber and diagnostics located around the chamber. The CIR and associated ground systems offer the Principal Investigator (PI) the opportunity to participate directly with their experiment on-board the ISS through remote operation and direct observation. Once a test point has been completed, the PI is be able to assess the results and provide information for automated changes to expedite technological advances. Ground systems will also enable the scientist to interact with other researchers at other locations.

ISS FCF in U.S. Lab Module Mockup



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Section 2 CIR System Design

A.2 CIR System Design

A.2.1 CIR MISSION

Although combustion is vital to our current way of life, researchers still lack a full understanding of many fundamental combustion processes. Here on Earth, gravity plays a role in why flames "shoot upwards", smoke rises, and large air circulation currents are established. These effects can mask many of the physical processes that occur, preventing researchers from understanding what exactly is happening. In the absence of gravity, combustion takes place in a very different manner than in the "1-g" environment we experience here on Earth. The ability to conduct controlled experiments without the complications resulting from gravity provides scientists with an opportunity to examine these complicated processes closely. A microgravity environment also permits larger and longer experiments, which allows more detailed observation.

The objectives of NASA's microgravity combustion science program are to improve understanding of fundamental combustion phenomena affected by gravity, to use research results to advance combustion science and technology on Earth, and to address issues of fire safety in space. Combustion research in the microgravity environment of the International Space Station may lead to enhanced energy efficiency, reduced pollution, and improved processes for making high-technology materials. The microgravity combustion science program supports research in how flames ignite, spread, and extinguish under microgravity conditions.

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A.2.2 CIR SYSTEM OVERVIEW

The CIR provides sustained Combustion physics research in the microgravity environment of the ISS. Investigators use this microgravity environment to isolate and control gravity-related phenomena, and to investigate processes that are normally masked by gravity effects and thus are difficult to study on Earth. Combustion microgravity experiments can provide a unique insight into the control of the generation of combustion by-products (pollution) and the increase efficiency of fuels.

The CIR systems are as follows:

- Optics Bench
- Combustion Chamber
- Diagnostics
- Fuel Oxidizer and Management Assembly
- Exhaust Vent System
- Experiment Specific Hardware
- Structural/Mechanical (ISPR/Door/ARIS)
- Electrical Power System
- Environmental Control System
- Command and Data Management System (Input/Output Processor, Image Processing & Storage, Software, Laptop)

The hardware overview of the Fluids Integrated Rack (FIR) is shown in the following figure.

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DESIGN CRITERIA

A.2.2.1 Design Goals

The underlying concept of the FCF of the FCF System and the CIR is to provide the infrastructure needed to perform the majority of Basis Experiments described in the SRED. For each experiment, a small amount of additional hardware will be developed by each experiment-specific hardware development team. Within that framework, the CIR design goals are to:

1. Provide a system (documented and fully qualified hardware and software (for flight and ground elements) augmented with experiment-specific hardware and software) which meets all requirements defined by the SRED, by applicable ISS and STS documentation, and by applicable experiment-specific SRDs;
2. Fulfill the CIR purpose (as stated above); and
3. Utilize the desired concept approach (as noted above).

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A.2.2.2 Design Guidelines

The SRED defines typical research from the microgravity science community and is intended to provide sets of requirements against which common hardware and software can be designed and mission success measured. The following guidelines have been used during the evolution of the CIR design:

- The CIR design will remain within applicable resource limits (including FCF generated margins); any exceptions will be identified in the risk management system and a strategy for resolution will be implemented.
- A minimum of 2 resupply flights per year is assumed.
- A goal of 50 kg average up-mass per experiment (not to exceed 100 kg).
- The CIR will utilize the ISS nitrogen supply.
- The CIR will have access to a minimum of a half rack of unpowered on-orbit stowage.
- The moderate temperature coolant flow rate is 97.5 lbm/hr per kilowatt, with a minimum coolant flow of 100 lbm/hr provided.

A.2.2.3 Major Components

The CIR systems, shown in Figure 4.1, are as follows:

- Optics Bench
- Fuel Oxidizer and Management Assembly (FOMA)
    - Exhaust Vent System (Combustion by-product “scrubber”)
- Combustion Chamber
- Replaceable Science Diagnostics
- Avionics
- Power System
- Replaceable Experimenter/Researcher Specific Hardware

Each of these systems will be discussed in detail in this section of the BSD.

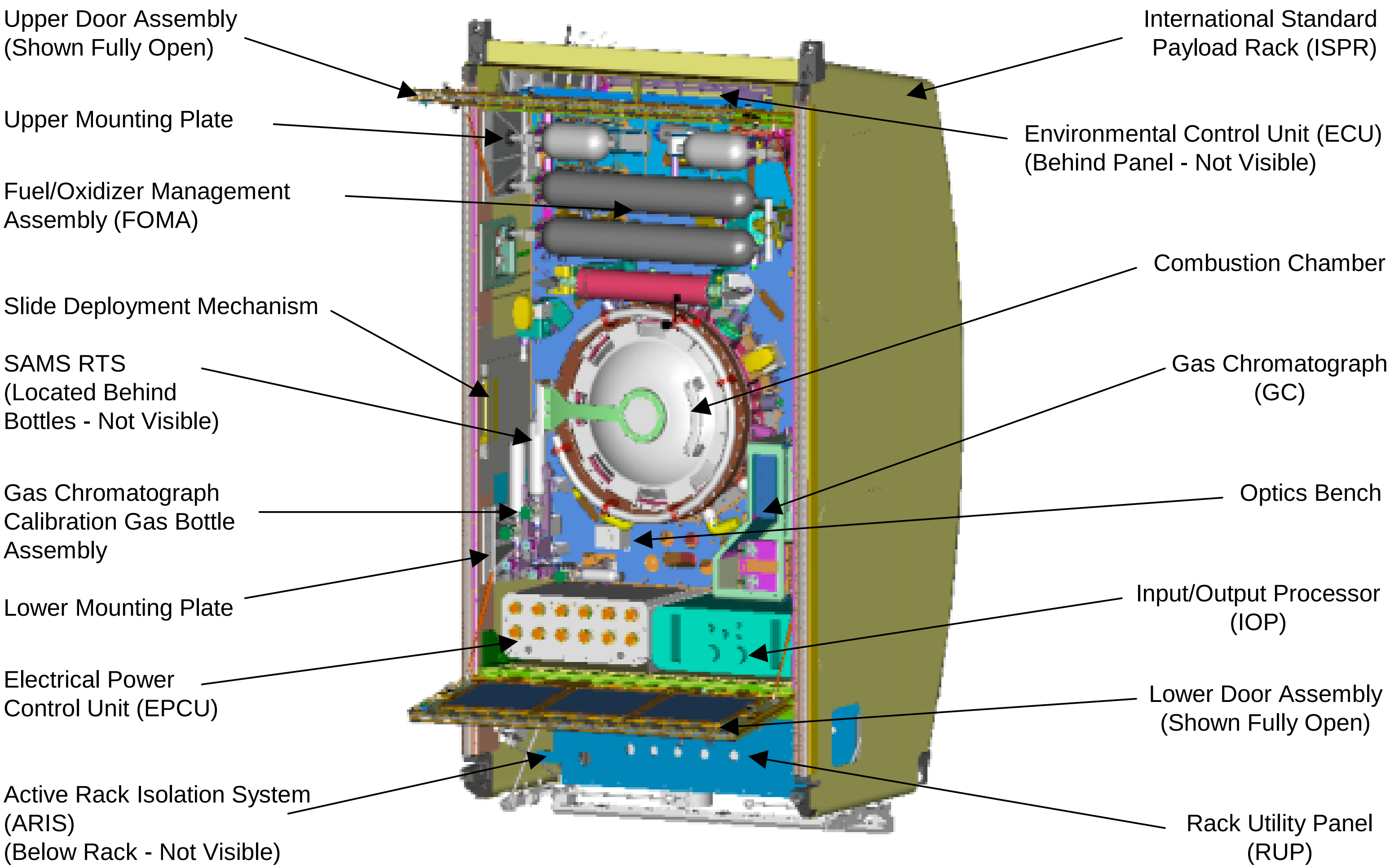
The CIR utilizes the following common hardware:

- International Standard Payload Rack
- Command and Data Management System
- Environmental Control System
- Active Rack Isolation System (ARIS)

These common systems are discussed in detail Appendix D.

The following figure illustrates the Combustion Integrated Rack.

Combustion Integrated Rack (CIR)



A.2.2.4 Optics Bench

Description

The Optics Bench, shown in Figures 4.4 and 4.5, provides structural support, electrical connections and mounting locations for all science support hardware. The Chamber Package (CP), Fluid/Oxidizer Management Assembly (FOMA), Science Diagnostics (SD) and PI Specific Electronic Package are mounted on the Optics Bench. The bench is mounted on slide assemblies for fold down to facilitate access. The Optics Bench is attached to the rack at four points using six M12x50 Long socket head cap screws for launch and landing loads. On orbit, the Optics Bench is restrained by a three-point attachment of slide pins.

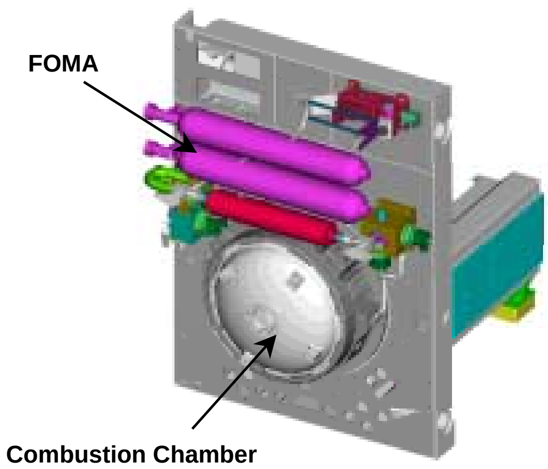
Features

- Tubing and wiring internal to the bench
- Folds down for full access
- Two slide assemblies provide translation and rotation of Optics Bench for deployment from the rack for diagnostics reconfiguration
- Internal fiber optics cabling technology incorporated
  - Capable of data rates up to 1 Gbit/s
- Diagnostics can be easily replaced/interchanged
  - 9 Universal Mounting Locations (UMLs) provide mechanical and electrical interfaces between diagnostics packages and bench
  - Precision alignment to the center of the chamber for the installation of the diagnostics packages
  - Diagnostics Packages to be positioned for alignment within 100 microns accuracy to the center of the chamber
- Front electrical interface for rapid diagnostics/image processing package configuration
  - Patch panel configuration connectors at the front of the optics bench allows for connections between diagnostic/IPP locations or to packages external to the optics bench/CIR
- Front access to PI hardware
- Gas bottles, exhaust vent filters and manifolds mounted on the front for easy replacement /maintenance.

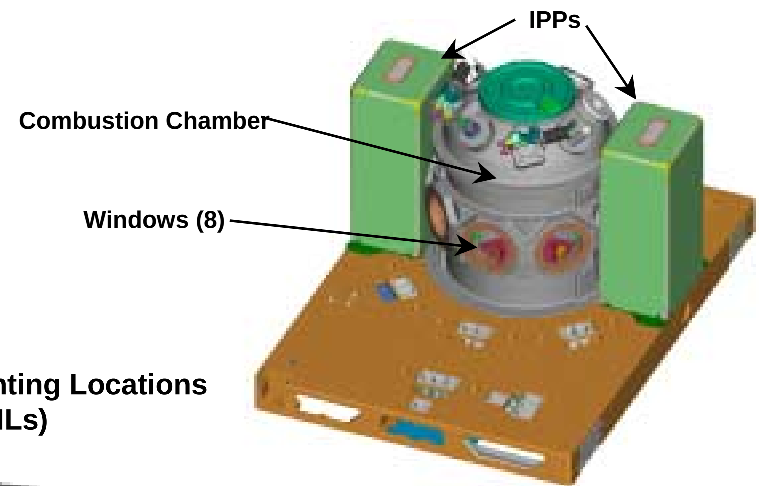
The following figure illustrates the CIR Optics Bench with components; the next figure illustrates the internal structure and cover of the CIR Optics Bench.

Optics Bench

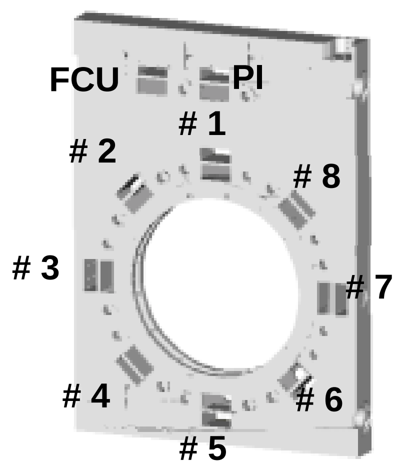
Front View



Back View



Universal Mounting Locations (UMLs)



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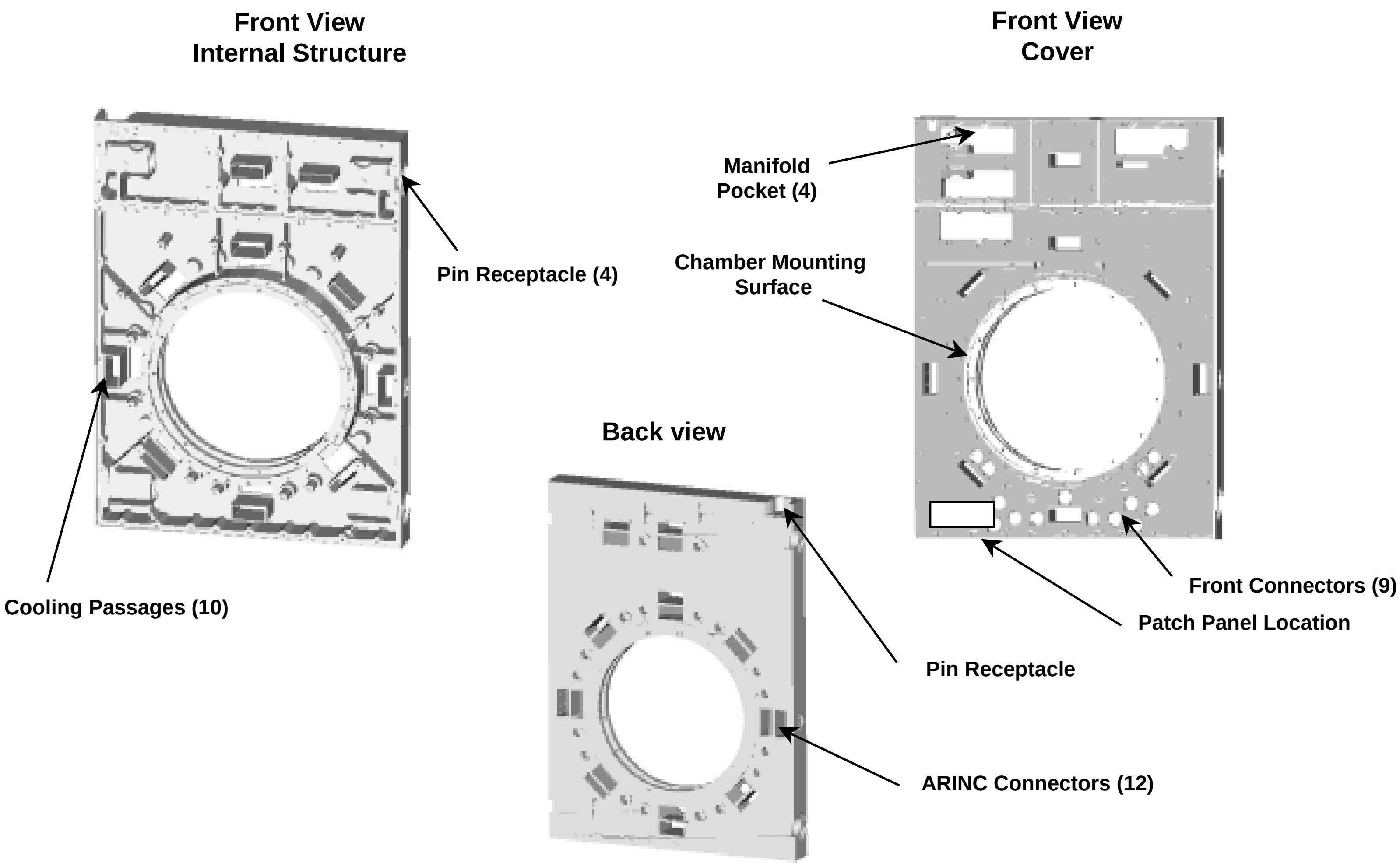
Optics Bench



A.2.3.4 Optics Bench (cont.)

Specifications - Mechanical

- 6061-T6 Aluminum
- 90.2 cm (W) x 124.5 cm (L) x 10 cm (D)
- Surface finish
  - Electroless nickel finish per QQ-C-320 and MIL-C-23422
  - Iridited contact surfaces for EMI grounding, where necessary
- UMLs
  - Maximum allowable volume:
    - 290mm x 230mm x 500 mm at UMLs # 2, 4, 6 & 8
    - 250mm x 360mm x 580 mm at UMLs # 1, 3, 5 & 7
    - 270mm x 264mm x 309 mm at UML #9
  - Avionics air cooling at all UMLs
- 100 mm x 40 mm opening providing up to 1.5 meters^3/min of air flow at 100 Pascal differential pressure. This flow translates to 450 W maximum cooling capability with a 15° C air temperature rise.

(Note: The cooling capability design point for the CIR is 2000 W, below the total maximum cooling capability for all the UMLs; also, UMLs not used will be blocked).

Specifications - Electrical

Electrical Connectors (Front of Optics Bench)

- 4 MIL-C-38999 connectors allow connections between PI Box and chamber.
  - Two connectors provide 89 #22 twisted pairs (total).
  - One connector provides 27 #20 twisted pairs.
  - One connector provides 2 coaxial, 4 fiber optic, and 5 #16 twisted pairs.
- Two – 100 contact MIL-C-38999 connectors provide 12 #22 pairs to each UML for custom use.
- Patch panel provides 4 fiber optic cables to #1 and even UMLs and 8 fiber optic cables to odd UMLs.

Electrical Connectors (Back of Optics Bench)

- One ARINC connector with 106 #22 contacts and 26 #16 connects at all UML locations.
- One ARINC connector with 26 #16 contacts and one with 212 #22 and 57 #20 contacts at the PI location.
- One ARINC connector with 106 #22 contacts and one with 212 #22, 25 #20 and 4 #16 contacts at the FCU.

Power Capabilities

- 2-8A, 28V at UML #'s 3, 5 and 7; FOMA Control Unit location; PI location; and Chamber via PI location
- 1-8A, 28 V at UML #'s 1, 2, 4, 6 and 8
- 3-4A, 120VDC available for PI use

The following figure summarizes the Optics Bench UML electrical connections.

COMBUSTION INTEGRATED RACK

Optics Bench Universal Mounting Locations Electrical Connections

	UML-1	UML-2	UML-3	UML-4	UML-5	UML-6	UML-7	UML-8	PI	IRR
8A, 28v Power Circuits	1	1	2	1	2	1	2	1	2	2
Ethernet Interface	1	1	2	1	2	1	2	1	1	0
Fiber Optic Lines	4	4	8	4	8	4	8	4	5	4
Camera Sync Interface	1	1	1	1	1	1	1	1	1	0
CAN Bus Interface	2	2	4	2	4	2	4	2	2	0
UML Location Identifier (6 bits)	1	1	2	1	2	1	2	1	0	0
Coaxial Lines	0	0	0	0	0	0	0	0	2	2
Differential Video (Line Pairs)	1	1	2	1	2	1	2	1	3	
Miscellaneous Lines (UML to O. B.)										
#22AWG Wires	24	24	24	24	24	24	24	24	178	200
#20 AWG Wires	0	0	0	0	0	0	0	0	27	55
#16 AWG Wires	0	0	0	0	0	0	0	0	10	15

NOTE: Each IPP contains two IPSUs, each controlling a camera diagnostic package.

Each IPSU interfaces to one 8A, 28V power circuit, one ethernet connection, four fiber optic lines, one CAN Bus interface, one camera sync interface, one differential video connection to the IOP and one set of UML Location Identifier bits.

Currently defined diagnostic packages require one 8A, 28V power circuit, one fiber optic line, one CAN Bus interface, one camera sync interface and one set of ULM Location Identifier bits.

8A power circuits are provided by paralleling 4A circuits in the cable harness between the EPCU and the optics bench.

All UML locations can be connected to other UML locations or connected outside the CIR rack via fiber optic connections to the patch panel located on the front of the optics bench.

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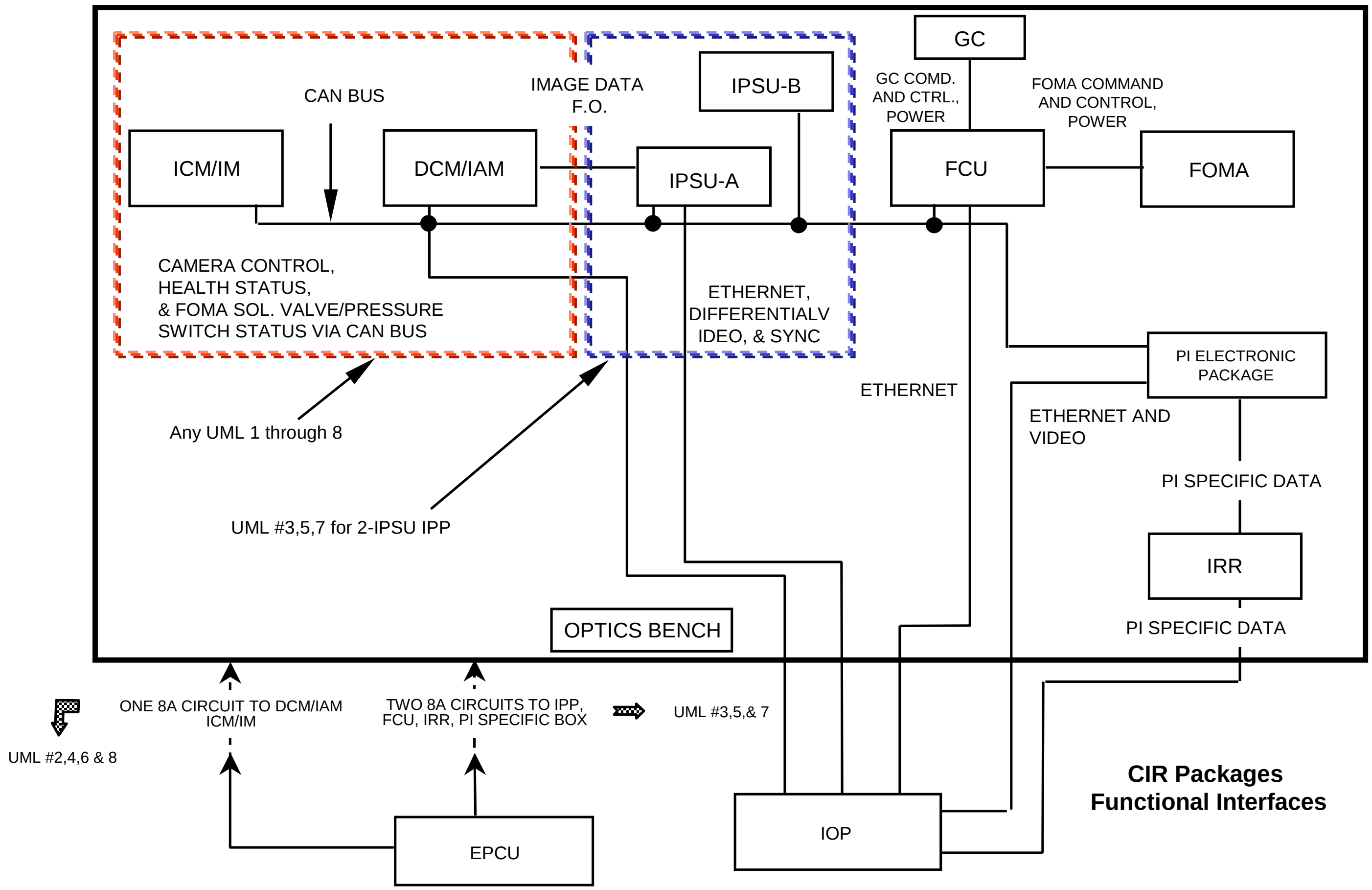
The following figure diagrams the Optics Bench internal wiring.

Optics Bench Internal Wiring



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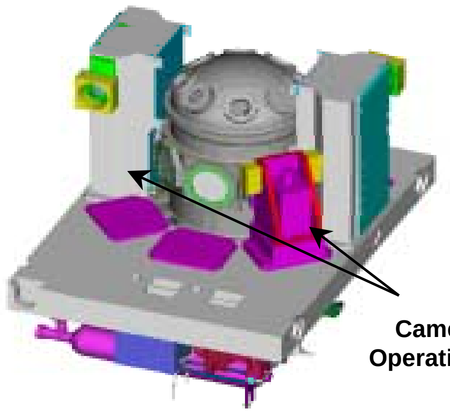
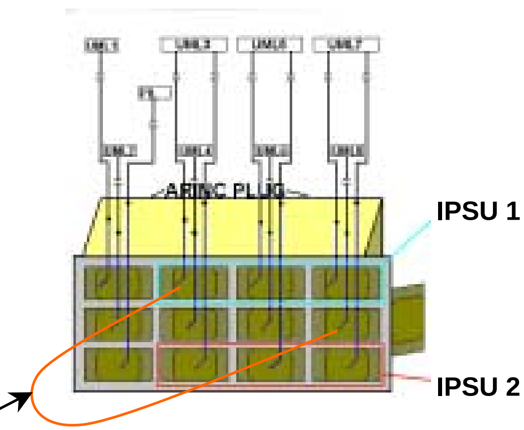
The following figure illustrates examples of reconfigurations for the CIR Optics Bench.

Optics Bench Reconfiguration Examples

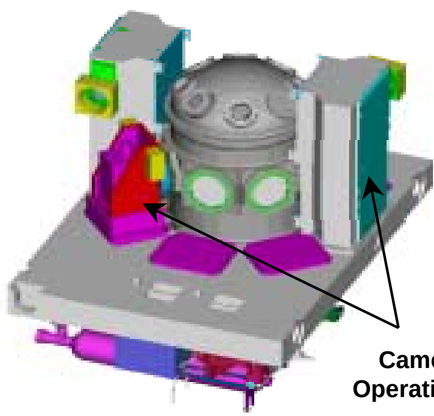
Diagnostics Configuration 1



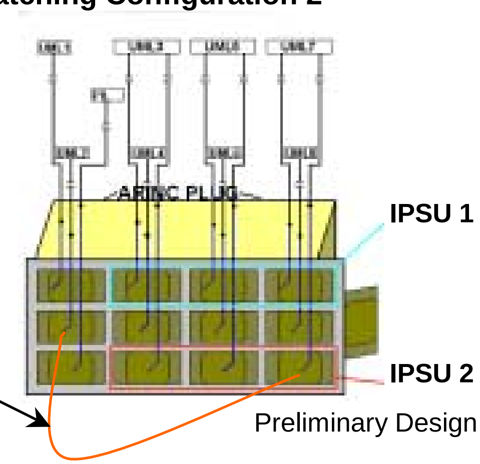
CIR Patch Panel
Patching Configuration 1



Diagnostics Configuration 2



CIR Patch Panel
Patching Configuration 2



A.2.2.4.1 Combustion Chamber Package

Description

The Combustion Chamber is cylindrical in shape with domed end caps. PI Unique Hardware slides into the Combustion Chamber through the front and is locked into position. PI Unique Hardware electrical and fluid connections are established at the Interface Resource Ring (IRR). The Chamber door is an 8 tab breech device for easy opening and PI Unique Hardware installation.

The Diagnostic Packages are arranged around the outside of the test chamber, and are aligned to view the interior of the test chamber through optical windows. Eight windows symmetrically located around the chamber provide optical access for the Diagnostic Packages. The windows are removable from inside the chamber for service and change out. This allows the use of alternate window materials with various wavelength transmission characteristics.

Features

- Provides structural support for the PI Hardware with on orbit access for installation and removal
- Breech lock hinged front lid. No tools required to open
- Windows replaced from the inside
  - No tools required for replacement
  - Racheting mechanism for vibration resistance
- Interfaces internal to chamber provided through the IRR
- Rear end cap with optional access ports
- Operational at ambient temperature

Specifications

Mechanical

- Material: 7075-T7351 Aluminum
- Dimensions: 400 mm (ID) x 900 mm (L); 100 free liters
- Mass: 138.85 kg
- Eight windows 115 mm viewing diameter
  - 4 pairs 180 degrees apart
  - Baselined optical material: Fused silica (For UV and visible)
  - Materials for transmission in the min. IR and far IR are being investigated.
- IRR interfaces
  - 4 electrical connectors
  - 2 ports for water cooling
  - 2 thermistors, 2 pressure transducers, 1 pressure switch
  - Gas delivery ports
    - Nitrogen
    - Gaseous fuel/premixed
    - Partial pressure mixer
    - High pressure supply
    - GC sampling
    - Exhaust vent port
- 827 kPa (120 psig) Maximum Design Pressure (MDP)
  - Meets pressure vessel safety requirement
- Rear end cap ports
  - 2 - 75 mm diameter openings as optional ports
  - 1 - 222.17 mm diameter center plug
  - 2 pressure transducers, 2 thermistors, and 2 pressure switches
  - Exhaust Vent Package return

Electrical

- 4 - shell 25 MIL-C-38999 round connectors
- 2 - 100, size 22 contacts
- 1 - 55, size 20 contacts
- 1 - 22 size 16 contacts (2 coaxial, 4 fiber optics, 15 electrical)

The following figure illustrates the Combustion Chamber

Combustion Chamber

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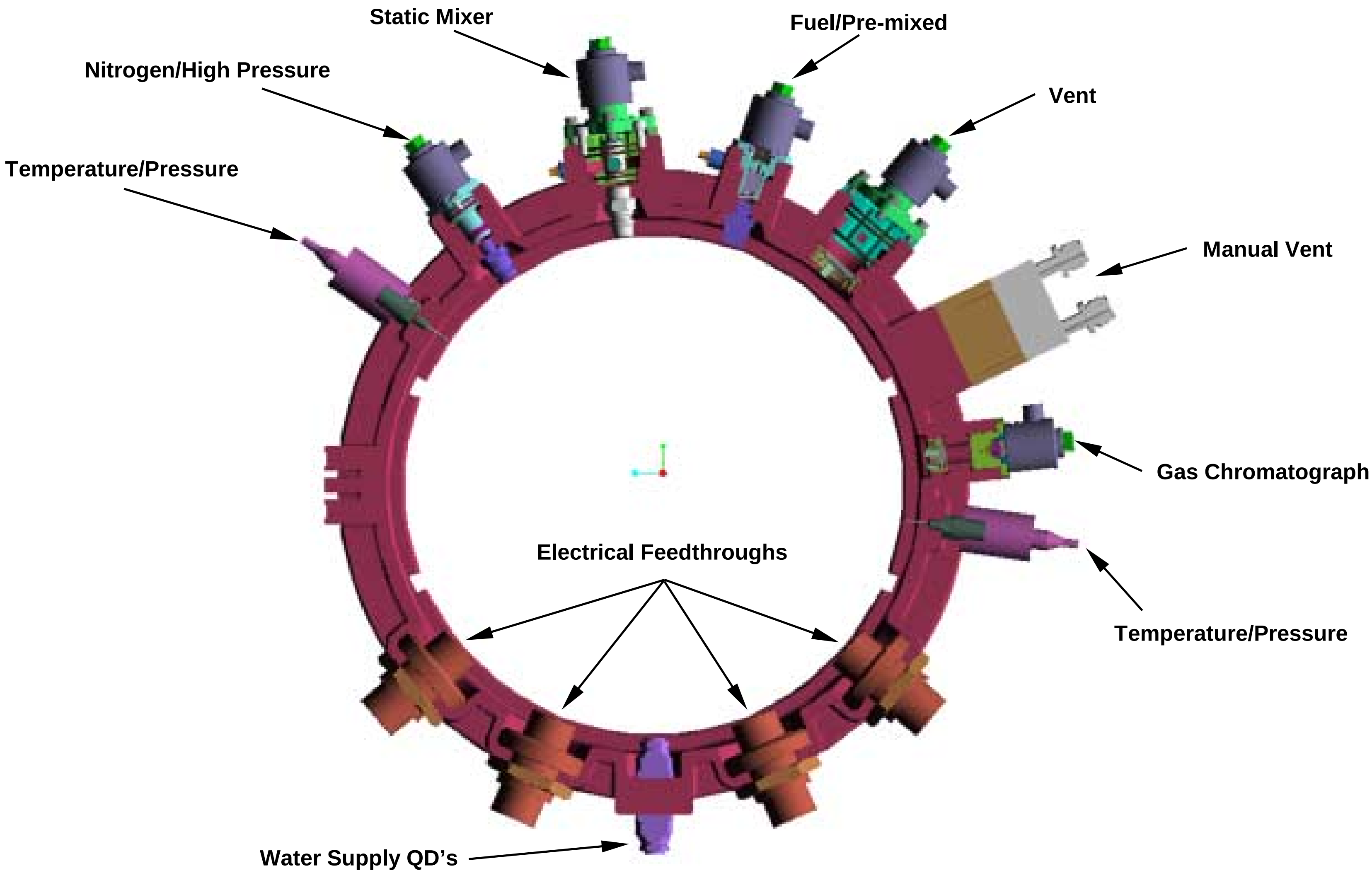
The following figure illustrates the Combustion Chamber Interface Resource Ring.

Interface Resource Ring



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The following figure illustrates the Combustion Chamber window assembly.

Window Assembly

A.2.2.4.2 Fuel/Oxidizer Management Assembly (FOMA)

Description

The Fuel/Oxidizer Management Assembly (FOMA) provides the ability to safely deliver all gaseous fuels, diluents, and oxidizers required to perform combustion experiments in the Combustion Integrated Rack (CIR) test chamber. The FOMA can also sample the test chamber environment via a Gas Chromatograph and control the venting of chamber gases, at acceptable concentration levels, to the International Space Station Vacuum Exhaust System (ISS VES).

The FOMA is comprised of two packages, the Gas Delivery Package (GDP) and the Exhaust Vent Package (EVP), which includes the Gas Chromatograph (GC). Each package is described in detail in the following sections.

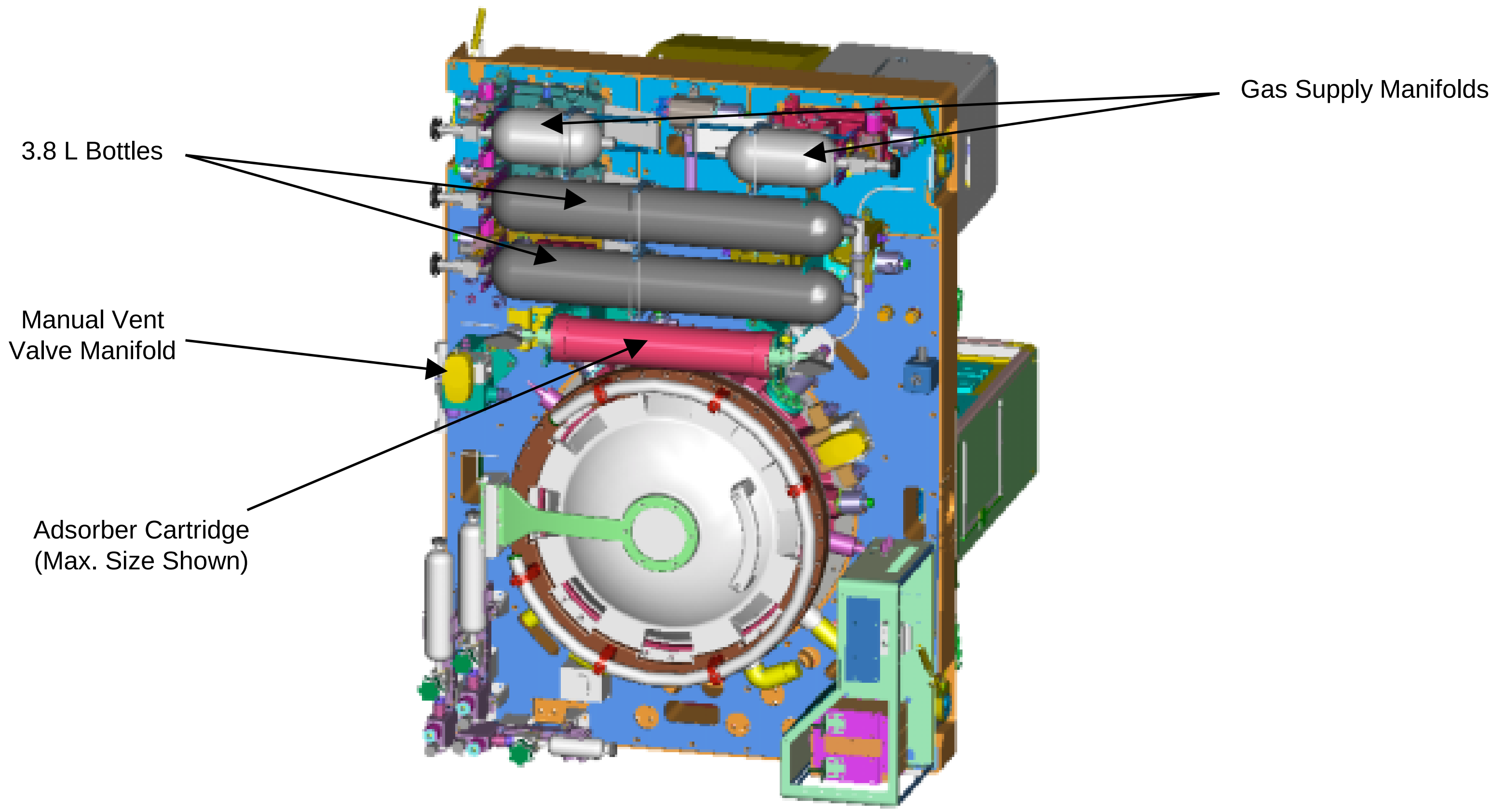
The desired gases are supplied by the Experiment in 3 bottle sizes, which are 1.0 liter, 2.25 liter and 3.8 liter. These gases can be either pure or pre-mixed. The FOMA provides the interface for the bottles as well as ISS supplied nitrogen. The crew will be able to change out the bottles when required. The FOMA also controls the regulation of gas to the Combustion Chamber.

On-orbit gas blending will accomplished by two methods, partial pressure and dynamic mixing. Both of these methods can be used to pressurize the Combustion Chamber to the desired pressure and gas ratio. The dynamic mixing method can accommodate experiments requiring flow through.

The Exhaust Vent Package connects the Combustion Chamber with the ISS VES. The package includes the Experiment supplied adsorber cartridge and a recirculation loop to convert post-combustion gases into species that are acceptable to vent or improve the test gas environment for the next PI hardware test. The adsorber cartridge may be required to remove water and filter particulates, absorb trace amounts of unspent fuels, and chemically alter some trace species (e.g. CO to CO_2). The GC will be used to verify the post-combustion gases meet ISS VES requirements prior to venting overboard.

The following figure illustrates the CIR FOMA components.

FOMA Components on the Optics Bench (front side)



A.2.3.4.2 Fuel/Oxidizer Management Assembly (FOMA) cont.

Safety Considerations

The FOMA utilizes multiple fault tolerancing to meet the safety requirements for flow, pressure and velocity. Normally closed redundant valves along with pressure switches, transducers and other sensors provide safe delivery of the specified gases. Bottles will be labeled and have a color-coded keyed plate to prevent inadvertent installation of an incorrect gas bottle. The fuel line is completely isolated from the oxidant line. Gas velocity through Oxygen supplied lines does not exceed 100 ft./sec. The EVP has the ability to perform an emergency manual vent of the chamber contents.

Features

- Capable of mixing 3 gases
- Utilizes ISS nitrogen
- Gases supplied by using multiple bottle sizes:
  - 3.8 L
  - 2.25 L
  - and /or 1.0 L bottles
- Bottle pressure up to 14 MPa (~ 2000 PSI)
- Static (Partial Pressure) blending
- Dynamic blending (mass flow controllers)
- High pressure supply directly from gas bottle
- Designed to clean: propane, n-hepthane, CO_2, sulfur dioxide, H_2O and others
- Use of manifolds to:
  - Minimize internal supply volume and reduce tube routing
  - Allow for modular assembly, maintenance and test

Specifications

- Gas Bottles Composition:
- 1.0L up to 85% O_2 @ 14Mpa (2000PSIA)
- 2.25 L up to 50% O_2@ 14Mpa (2000PSIA)
- 3.8 L up to 30% O_2@ 14Mpa (2000PSIA)

Gas Blending Accuracy

- Partial Pressure Method: Less than ± 0.2% absolute
- Dynamic Method
  - Oxygen Blends: < 25%: ± 1% absolute
  - Oxygen Blends: > 25%: ± 2% of reading

Gas Flow Rates

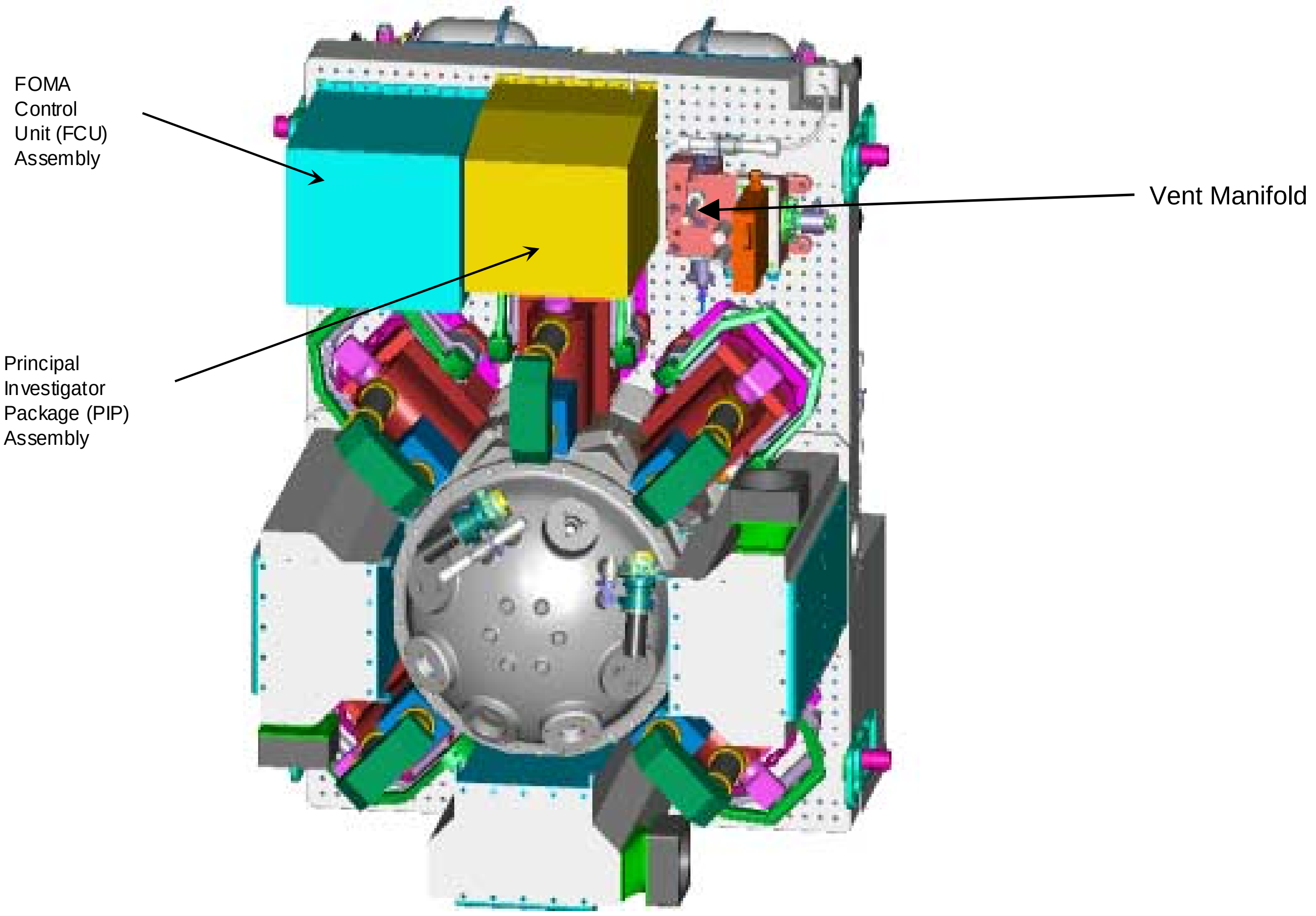
- Maximum from Each Supply (non-fuel): 30 SLM ± 1.0 SLM
- Maximum Possible (All Supplies - non fuel): 90 SLM ± 1.0 SLM
- Maximum Fuel: 2 SLM ± 1.0% of full scale

Test Chamber Pressure Limits

- Test Chamber Maximum Design Pressure (MDP) = 827 kPa (120 psig) Approx. 8 atmospheres
- Experiment-provided Sub-Chamber: Total pressure must by less than Test Chamber MDP if leaked
- Experiment-provided Sub-Chamber: Leak Before Burst (LBB) Design. Chamber pressure/volume must be less than test chamber MDP if leaked. Maximum pressure<14 MPa (2000 psia).

The following figure illustrates the FOMA Manifolds and Control Unit locations.

FOMA Manifolds and Control Unit Locations on the Optics Bench (Back Side)



A.2.3.4.2 Fuel/Oxidizer Management Assembly (FOMA) cont.

Exhaust Vent Specifications (Meets SSP 57000 Section 3.6.1 requirements):

- Maximum Outlet Pressure = 275.8 kPa (40 psia)
- Outlet Temperature = 16° - 45° C (60° - 117° F)
- Maximum Dew Point = 16° C (60° F)
- Combustion By-Products: Compatible with CIR and ISS VES

Concentration Limits:

- Most gases can be vented 100% by volume as long as analysis is performed to show that the vented atmospheres are compatible with materials and create no adverse reactions.

Adsorber Cartridge:

- Sizes/Weights:
- Diameters:

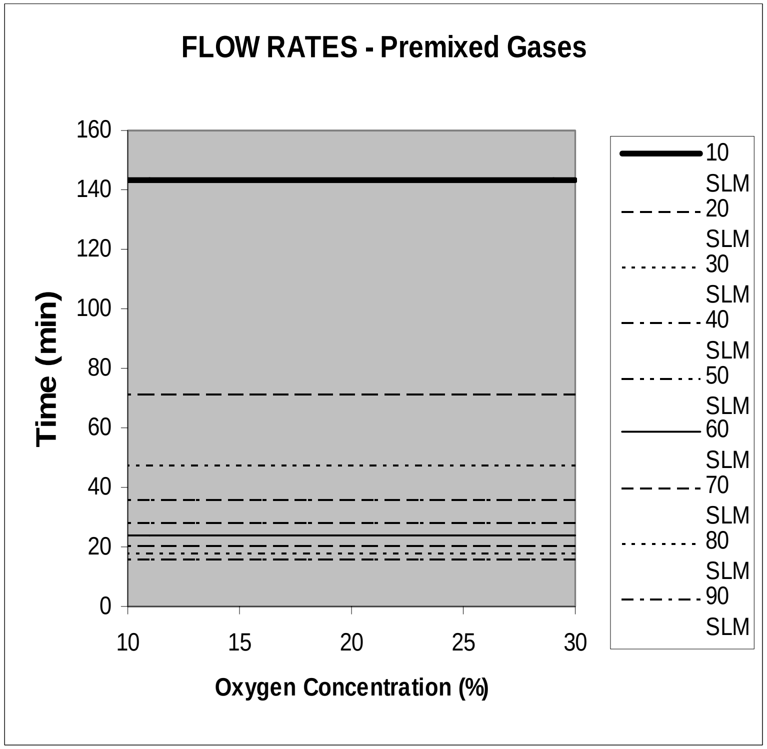
  51 mm (2 inches); 76 mm (3 inches)
- Lengths:

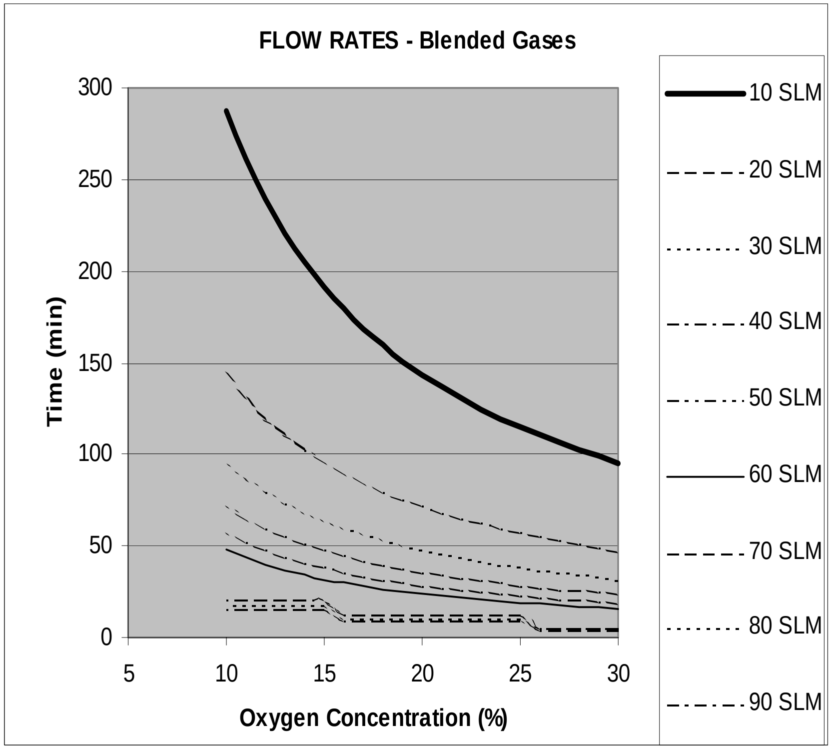
  203 mm (8 inches) 279 mm (11 inches) 256 mm (14 inches)
- Weights (empty):

  3 kg (6.6 lbs); 4.7 kg (10.3 lbs)
- Adsorbing Material:
- Lithium Hydroxide (LiOH), Density = 0.445 g/mL
- BPL Activated Carbon, Density = 0.47 g/mL
- Silica Gel, Density = 0.715 g/mL
- Molecular Sieve, Density = 0.705 g/mL
- Particulate Filters

The following figure illustrates the CIR FOMA maximum test duration for chamber oxygen concentrations at selected flow rates.

FCF CIR FOMA MAXIMUM TEST FLOW DURATIONS FOR CHAMBER OXYGEN CONCENTRATIONS AT SELECTED FLOW RATES





A.2.3.4.2 Fuel/Oxidizer Management Assembly (cont.)

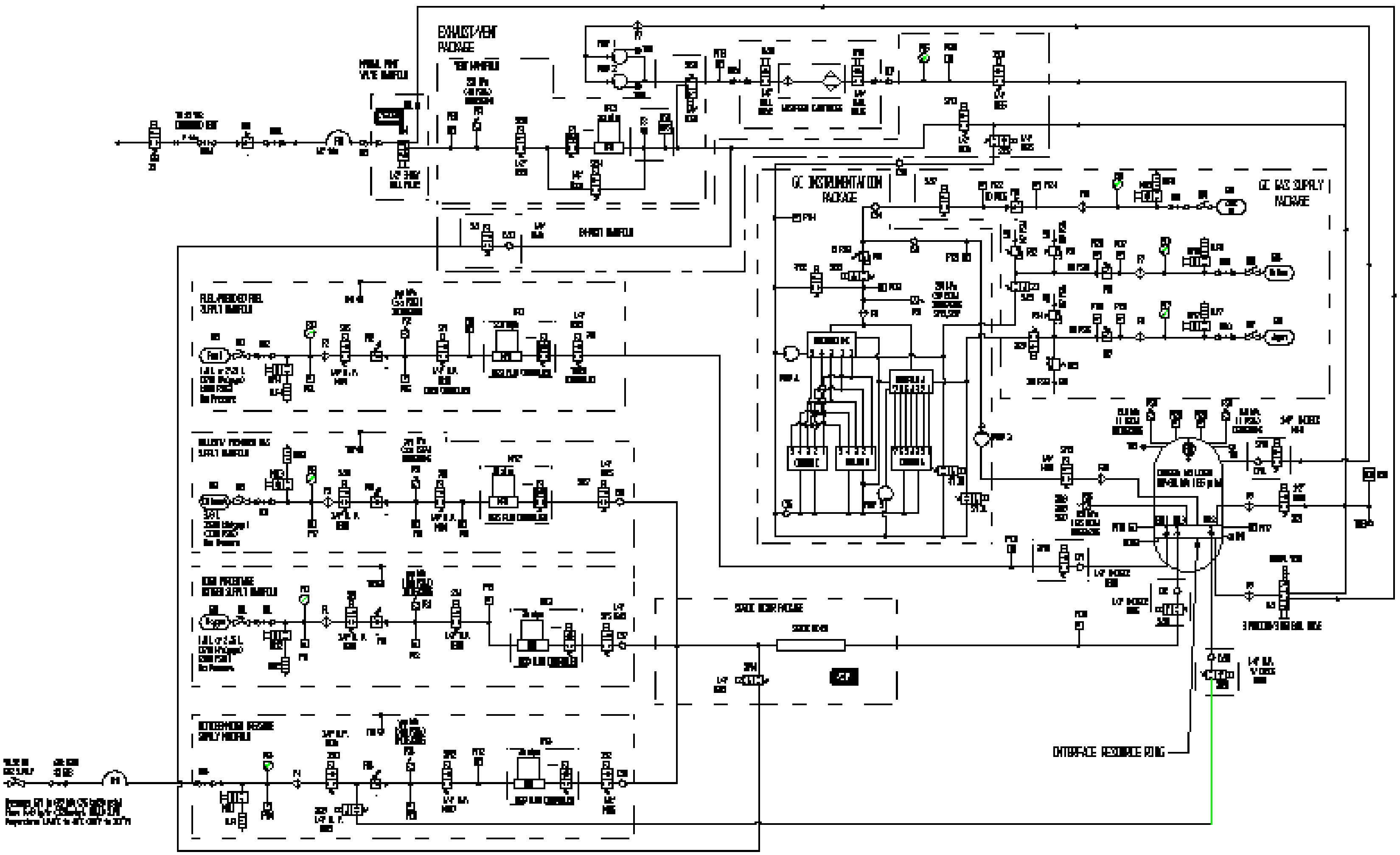
FOMA Schematic

The FOMA is shown schematically in the following figure. The FOMA, including the GC, solenoid valves, pressure transducers, pressure regulators, pressure switches, temperature sensors, mass flow controllers, pressure relief valves, manual valves, check valves, pumps, and miscellaneous fittings and quick disconnects.

The redundant valving is to meet safety requirements and to protect the bottled gas from being evacuated during venting. The pressure sensors and pressure switches are to assure that an over pressurization of the Combustion Chamber does not occur. All gases will be metered by the mass flow controllers. As an alternative, pre-mixed gas can be delivered to the Combustion Chamber directly from the supply bottle via the Nitrogen/High Pressure manifold.

The following figure illustrates the Fuel/Oxidizer Management Assembly mechanical schematic.

FOMA Schematic



A.2.2.4.2.1 Gas Delivery Package

Description

The Gas Delivery package (GDP) consists of gas supply bottles and the necessary hardware/instrumentation to distribute and regulate the gas delivery to the Combustion Chamber. The GDP provides for up to 3 consumable gases to be installed and distributed. The installed gases are for the active experiment only, any additional bottles required must be stowed.

An interface to the ISS supplied nitrogen will be utilized for experiment diluent, line purging and pressure/leak checking. The gases required for each experiment can be delivered to the test chamber by bottles or by the ISS (nitrogen only). The bottle sizes and typical gas constituents are listed below. The maximum pressure in each bottle, depending on the gases supplied, will not exceed 13,790 kPa (2,000 psia).

Specifications

The oxidizer and/or diluent type gases can be blended on-orbit by either partial pressure or dynamic blending techniques. Pre-mixed gases blended on the ground can be accommodated if the experiment requires an unique gas mixture or one that has a constituent accuracy exceeding the FOMA capability. Up to 3 different bottles (or 2 bottles and ISS supplied nitrogen) can be used to achieve the desired environment inside the Test Chamber. Fuel bottles will always be pure or pre-mixed and filled on the ground. The crew will be able to change-out these bottles when required.

“Static” or Flow-Through type experiments can be accommodated by the FOMA. For “Static” type experiments, the desired gaseous fuel mixture or environment (chamber atmosphere) can be provided by either partial pressure, dynamic mixing or pre-mixed bottles. For Flow-Through type experiments the desired flow over the combustion event can be delivered by metering of the Mass Flow Controllers (MFCs) in combination with “real-time” venting, or by the experiment providing fans/ducting of the “static” gas within the test chamber. Real-time venting is a once through flow method where flow is vented overboard and not re-circulated. Real-time venting is used for experiments which do not produce unacceptable gaseous byproducts or experiments that can have their byproducts cleaned to acceptable levels by a single pass through the adsorber cartridge.

Attachment ports inside the test chamber on the Instrumentation Ring allow for a more direct connection to the experiment. These ports also can facilitate the use of an independent chamber within the CIR test chamber if required. The sub-chamber must be of a leak before burst (LBB) design, and could be pressurized to greater levels than the CIR test chamber, as long as potential leaks can be dissipated safely.

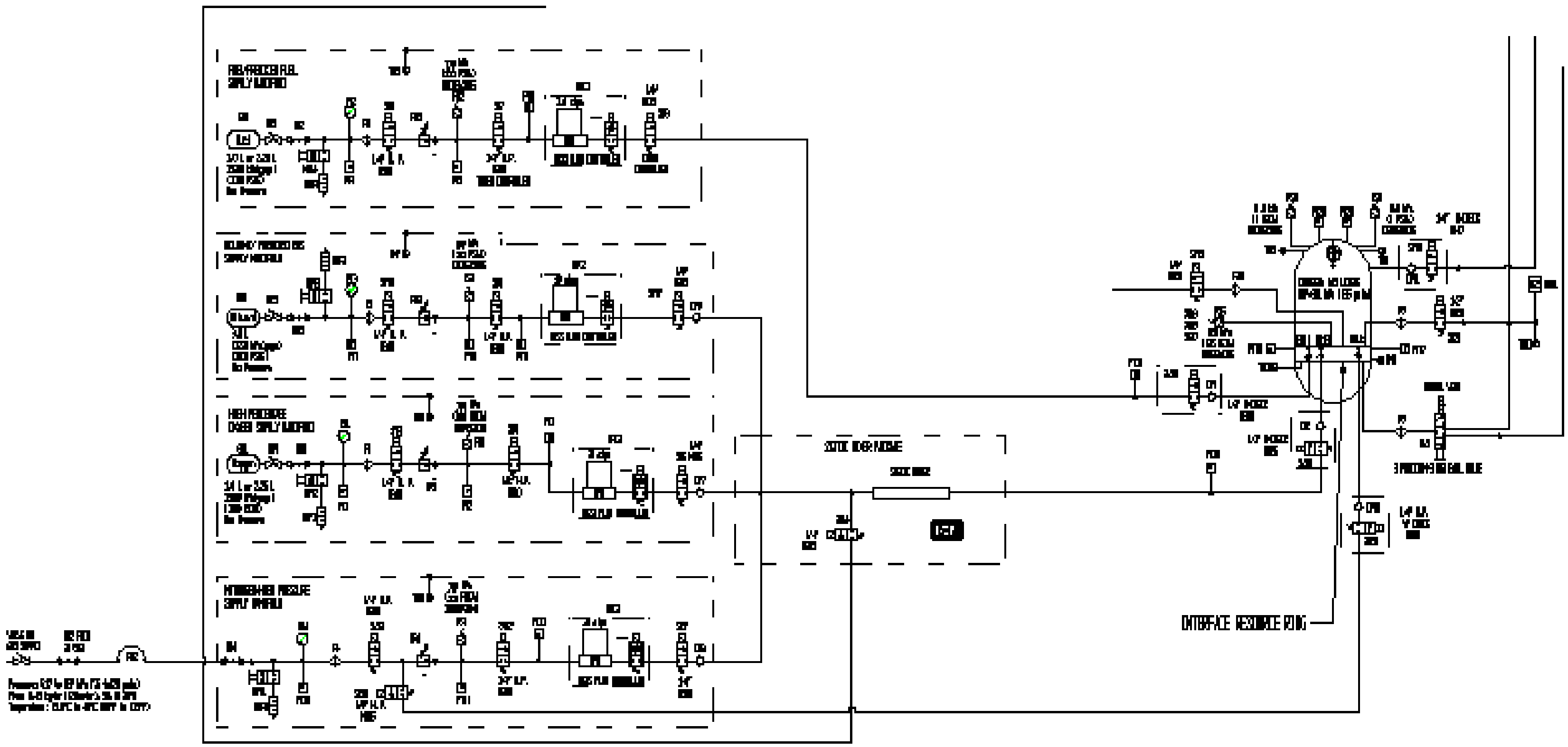
The gas will primarily be delivered to the chamber via bottles. The bottle sizes and constituent limitations are as follows:

- 3.80 Liter bottle: Diluents or oxygen/diluent blends with oxygen concentrations less than 30%
- 2.25 Liter bottle: Oxygen/diluent blends with oxygen less than 50% or Fuels/Pre-mixed Fuels
- 1.0 Liter bottle: Oxygen/diluent blends with oxygen less than 85% or Fuels/Pre-mixed Fuels

Manifolds containing regulators, valves, pressure sensors and Mass Flow Controllers (MFC) are used to regulate the flow of gas to the Chamber.

The following figure illustrates the Gas Delivery Package mechanical schematic.

Gas Delivery Package Schematic



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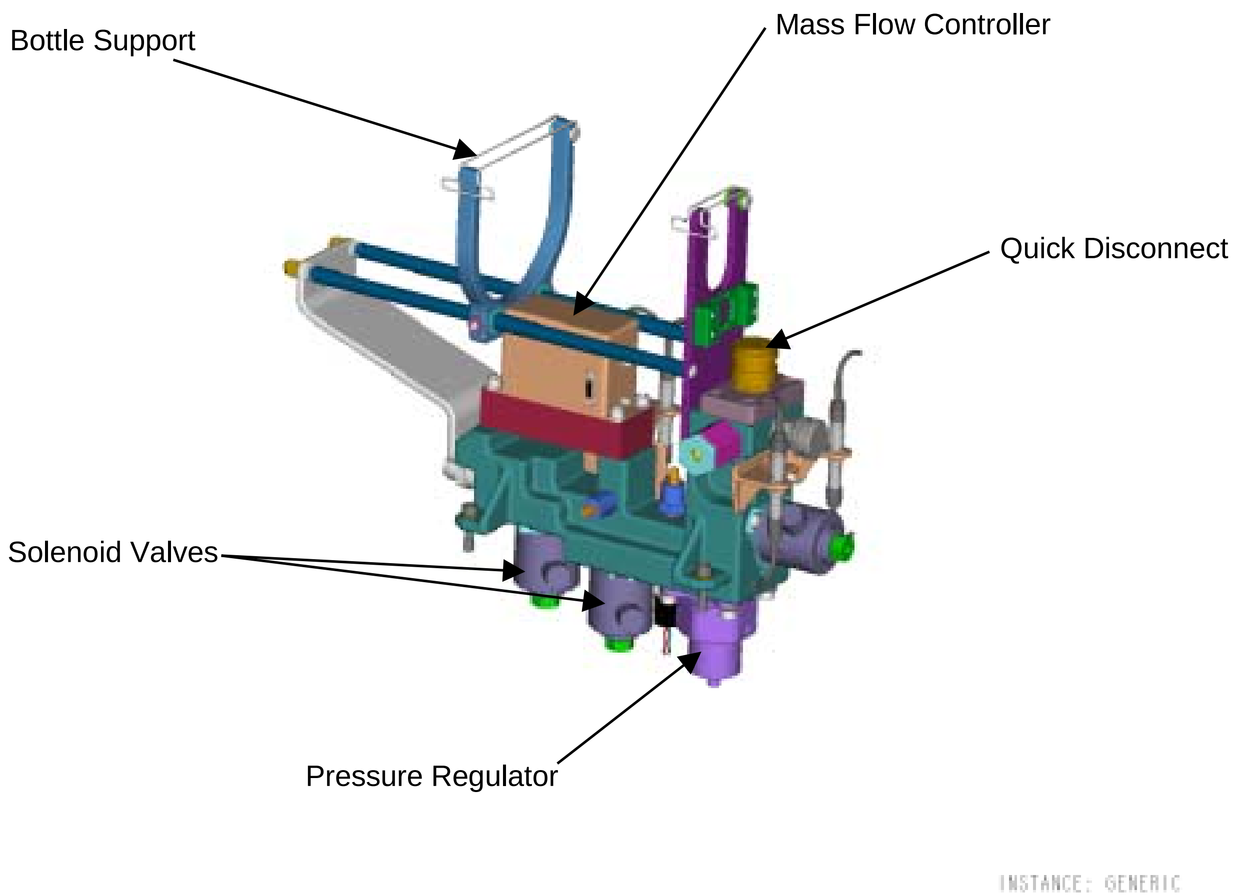
The following figure illustrates a model of the FOMA Manifold.

FOMA Manifold



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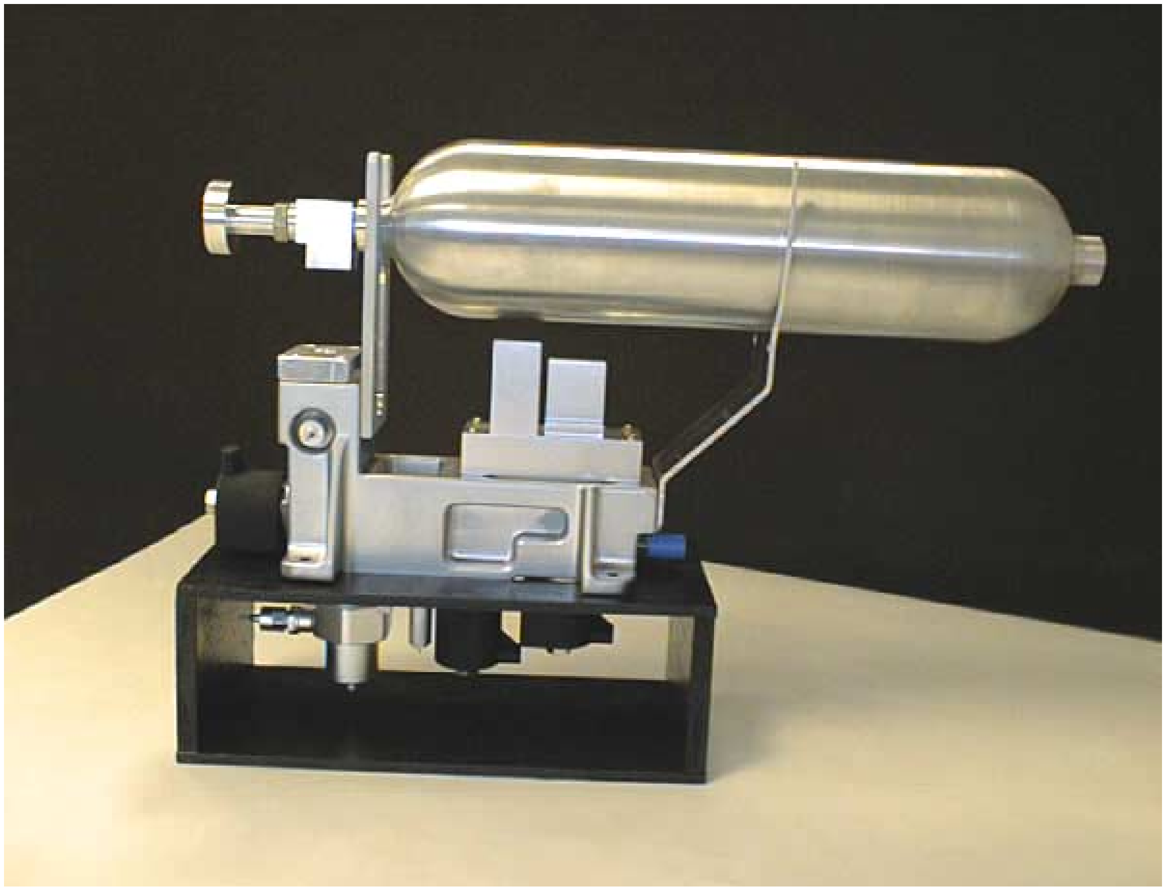
The following figure illustrates a rapid prototype model of the FOMA Manifold.

FOMA Manifold - Rapid Prototype Model



A.2.2.4.2.2 Exhaust Vent Package

Description

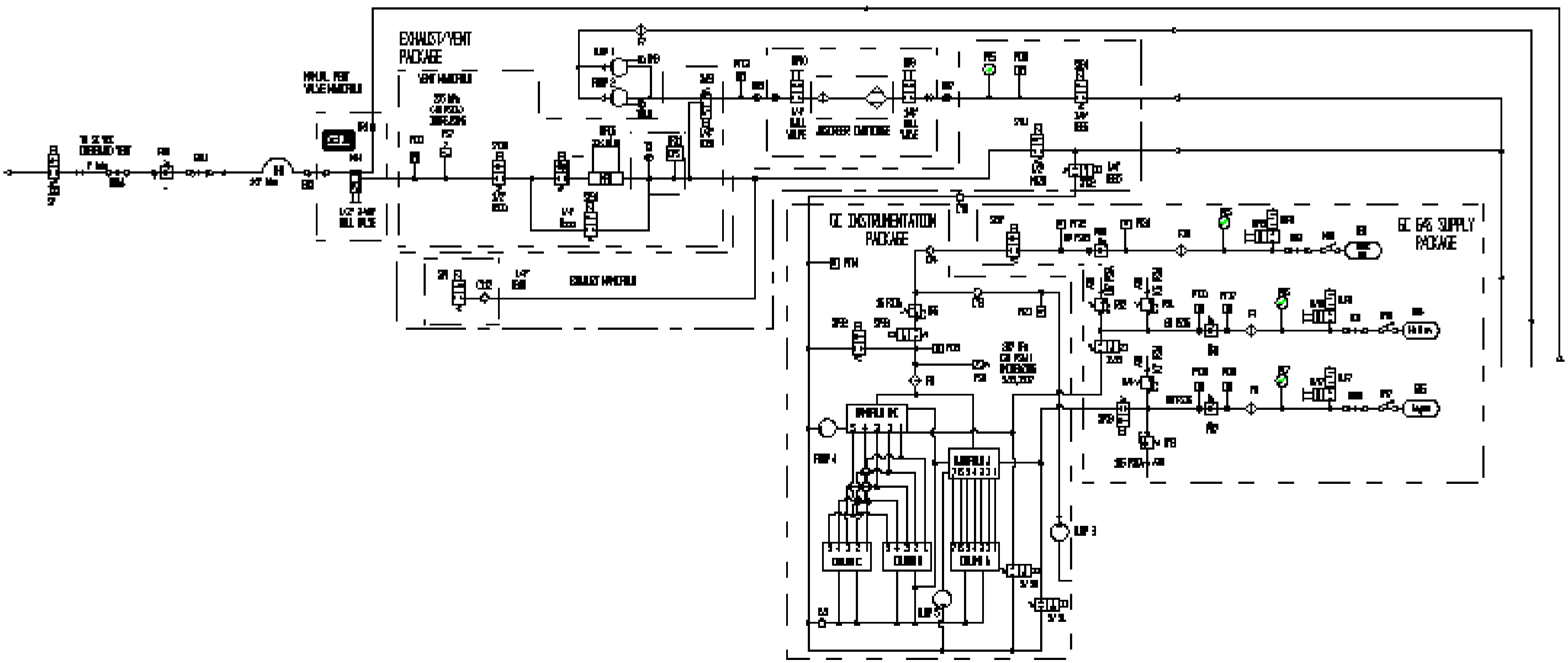
The Test Chamber environment can be purged, when necessary, by using the connection to the ISS VES. Prior to exhausting the gas/combustion by-products to the ISS VES, the gas must meet ISS requirements per SSP 57000 Section 3.6.1 for both concentration and contamination. The FOMA Exhaust Vent Package provides the ability to filter particles, convert post-combustion gases to acceptable levels, remove any moisture and allow for a recirculation loop in and out of the Test Chamber. The recirculation loop can be used before or after an experiment run. Cartridges filled with the appropriate adsorbing agents are used and replaced by the crew as required.

Gas Chromatograph

The Gas Chromatograph (GC) is used to sample gas from the combustion chamber. The GC has three independent separation columns with thermal conductivity detectors and utilizes two carrier gases, helium and argon. These carrier gases are delivered from 300 mL bottles at 12.4 MPa (1800 psia) provided by the experiment. A check gas is also experiment-provided in a single 75 mL bottle at a maximum of 12.4 MPa (1800 psia). The lower detection limit of the GC is 100 ppm (depending on the compound and gas mixture) with an expected accuracy of $\pm$2%.

The following figure illustrates the Exhaust Vent Package mechanical schematic.

Exhaust Vent Package Schematic



A.2.2.5 Science Diagnostics

Description

Seven diagnostic packages are planned:

- High Bit Depth/Multispectral Imaging Package (HiBMs)
- High Frame Rate/High Resolution Package
- Color Package
- Low Light Level - UV Package
- Low Light Level - IR Package
- Mid-IR Camera Package
- Illumination Package

The Diagnostic Packages are mounted on the Optics Bench using common interfaces to permit movement of packages to various window locations for maximum science support flexibility. Blind electronic, power and avionics connections are provided at the Optics Bench interface. This eliminates the need for manual cable reconfiguration. To provide minimum line lengths for EMI isolation, motor control and power conversion electronics are housed within the base of the package in the Diagnostic Control Module (DCM). The design approach emphasizes packaging modularity for operational flexibility and maintainability. Standardized optical interfaces (referred to as the flange mounts) are used between modules. These interfaces permit module arrangements to be reconfigured on orbit if required by science. A latch mechanism, which is activated by a latch tool, is incorporated into the DCM for attachment and removal from the Optics Bench.

Digital imaging systems are used where feasible to collect and store data of the highest possible fidelity. An Image Processing Package (IPP) supports a pair of imaging packages. Image Processing and Storage Units (IPSUs) support additional imaging packages. An optical fiber data link is used between the digital imaging packages and the image processors. Real time processing techniques are used for closed loop operational control of the packages. Images are stored on high-density disk drives for later downlink. Real time video is provided for experiment status monitoring purposes.

On-orbit change-out supports future growth. Entire packages can be replaced at the Optics Bench interface. This permits development and installation of new diagnostics such as a long wavelength infrared imager.

Modular design of the packages allows for performance and technology upgrades with minimal up-mass impact. For example, with modifications, the illumination package could support applications requiring Particle Image Velocimetry (PIV), Schlieren, or Interferometry.

The following figure provides a summary of the combustion diagnostics capability.

COMBUSTION DIAGNOSTIC CAPABILITY SUMMARY

Diagnostic Package	Imaging Physics	Derived Applications	PI Utilization	Pixels	Field of View	Resolution	Bit Depth (all digital)	Run Time	Frame Rate	Minimum Exposure Time	Spectrum	Sensitivity	Features
			note 7	note 2	mm	lp/mm Note 4	bits	minutes	frames/sec	milliseconds	nm	object radiance	note 8
HiBMs	Bkgrnd lum absorption Near IR Emissions Density Gradients	Soot Volume Fraction Soot Temperature Shadowgraph	c6, c7 c8, c11	1024 or Bin 512	50 & 80 dia. Telecentric	10 & 5.0 5 & 2.5	12	20 m @ 15 fps	15 Note 1	1	650-1050 Note 5	N/a 1200K – 2000K 0.8K/mm	Manual iris
HFR/HR	Short Exposure FOV Pointing	High Frame Rate High Resolution	c6, c8	Bin 512 1024	9 square Note 3 Telecentric	12 @ 50% mod. 20 @ 50% mod.	8 (12 avail. if binning)	20 m @ 110 fps 20 m @ 30 fps	110 Note 1 30 Note 1	1	450-750 Note 6	600 lux	Centroid Tracking Event Trigger Autofocus
Color	Visible Spectrum	Configuration Verification	All (except c9)	512x512	90 – 350 sq. Zoom	2.8 – 0.7	24	25 m @ 30 fps	30	0.1	400-700	20 lux @ f/3	Auto-iris Motorized focus
Low Light Level - UV	Short Wave Intensified	OH Emissions	c1, c2, c3, c4, c6, c8, c9, c10	Bin 512 1024	42 & 100 sq.	4.3 & 1.8 6.7 &2.8	8	40 m @ 60 fps 20 m @ 30 fps	60 30	10 ns	220-850	2x10E-7 ft-candle 1x10E-7 ft-candle	Manual iris Manual focus
Low Light Level - IR	Long Wave Intensified	H2O Emissions	c2, c5, c6, c7, c9, c10, c11	Bin 512 1024	45 – 180 sq. Zoom	4.3 – 1.1 6.8-1.7	8	40 m @ 60 fps 20 m @ 30 fps	60 30	10 ns	400-900	2x10E-7 ft-candle 1x10E-7 ft-candle	Auto-iris Motorized focus
MID-IR	Thermal	Absorption Lines Temperature	c1, c2, c3, c4, c8, c10, c11	320x244	183x138	0.9	12	200 m @ 60 fps	60	1	1000-5000	263K to 1773K	
Illumina-tion	W-Halogen Noncoherent Coherent	Calibration Bkgrnd Illum Interferometry	c5, c6, c7 c8, c11	N/A	80 dia. Collimated	N/A	N/A	N/A	N/A	N/A	3000K 675	5 mw output	Illumination Source Selectable

Note 1: External sync: can do time exposures.
Note 2: Binning, sub-area recording and auto-gain/saturation protection are available in the image acquisition system.
Note 3: This FOV is steerable within a 46 mm diameter field.
Note 4: At Nyquist limit.
Note 5: 10 nm bandpass; tunable to 1 nm. Allow 100 msec for switching. Removable for broadband operation or replaceable with RGB filter or 400-720 nm tunable filter.
Note 6: Provision for installation of tunable filters for multispectral or field sequential color imaging.
Note 7: PI Codes: c1 – Bahadori; c2 – Ronney; c3 – Spread Across Liquids; c4 – Altenkirch; c5 – Smoldering Combustion; c6 – Williams; c7 – Faeth; c8 – Choi; c9 – Cool Flames; c10 – Tien; c11 – TITSI.
Note 8: Autofocus is available with applicable PI software.

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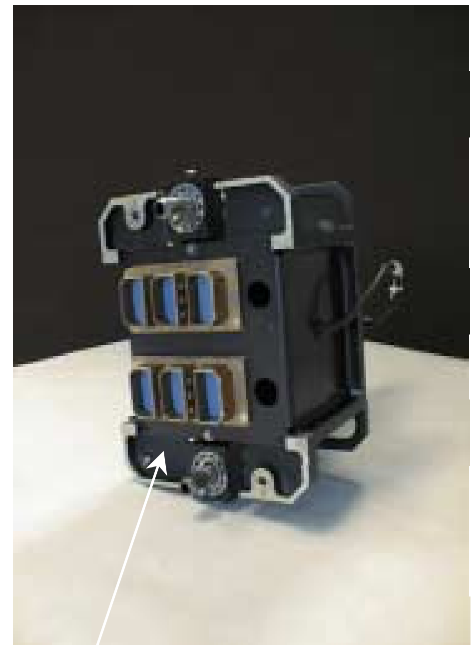
The following figure illustrates the science diagnostics camera bracket.

Science Diagnostics Camera Bracket

Side View/Latch

Camera/Optics

Bottom View



Optics Bench Mating
ARINC Connector

Electronics Enclosure

A.2.2.5.1 High Bit Depth/Multi-Spectral Imaging Diagnostics Package

Description

The HiBMs Diagnostic Package consists of a spectrally filtered telecentric imaging optical system and a high resolution 12-bit output digital camera. The modular package is designed for operational flexibility.

Specifications

Optical System

- Telecentric (no magnification change with object distance)
- 50 mm and 80 mm diameter Fields of View
- 10.0 and 5.0 lp/mm Resolution (0.1 and 0.2 mm, respectively)
- Numerical Aperture: 0.005 to 0.02. Aperture adjustment is manual.
- Focus 208 mm from inside surface of chamber window
- Depth of field: 71 mm @ NA 0.009
- PI-provided modules could be added that will support index gradient measurements.

Liquid Crystal Tunable Filter

- 10 nm FWHM bandpass
- 650-1050 nm spectral range
- 1 nm spectral resolution
- 15% transmittance @ 800 nm
- Average out-of band transmittance <0.01%
- 100 ms switching time between states
- Removable for broad spectrum imaging with insertion of the Filter Compensator Module.
- Could be replaced with a PI-provided RGB filter module for field sequential color imaging.

Camera

- Imager is 1024 X 1024 pixel monochrome progressive scan frame transfer CCD with 85% fill factor.
- Digital 12-bit signal output
- Frame Rate: programmable for external sync, 7.5, 15 or 30 frames per second
- Exposure time is user controllable with integration times of up to 1 second. Shutter speeds to 1/1000 second.
- Binning (2 x 2) is programmable to reduce data storage requirements or permit higher frame rate operations
- Sub frame image storage options are available in the acquisition system to reduce data storage requirements

System

- Programmable frame rate and exposure time options. Package can operate at a single wavelength or in an alternating wavelength mode.
- Maximum run time (12-bit output) 30 minutes at 10 fps and 20 minutes at 15 fps full resolution; 40 minutes at 30 fps binned.

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A.2.3.5.1 High Bit Depth/Multi-Spectral Imaging Diagnostics Package (cont.)

Application Note:

The Package can be programmed to measure two characteristics of soot producing flames:

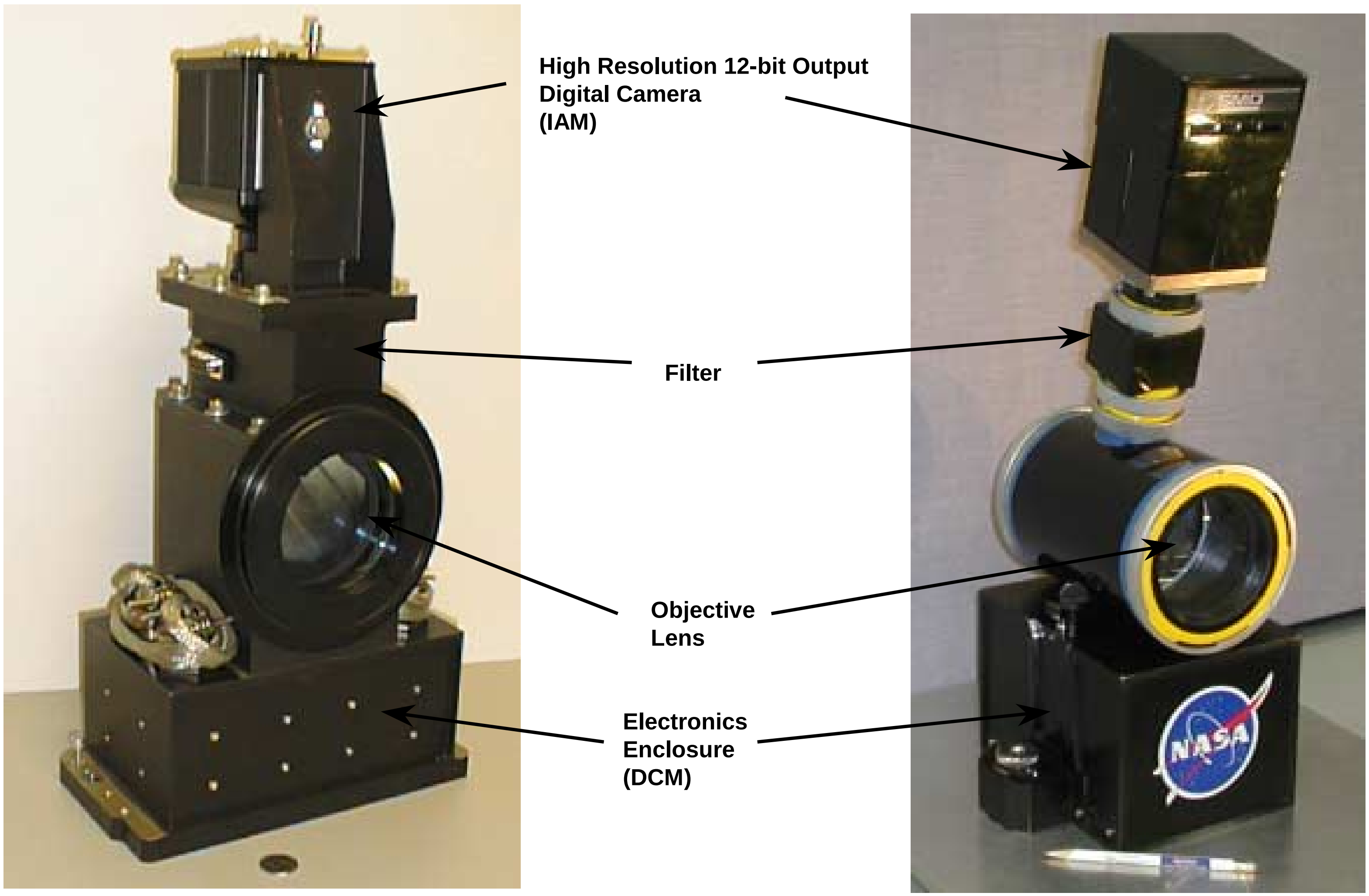
1. Soot temperature is measured using a two (or more) wavelength pyrometry technique;

2. Soot volume fraction is determined by measuring the percentage of laser illumination, from the Illumination Package, that is blocked by soot in the flame region.

Measurements are made at the wavelength of the illumination package laser diode (675 nm) and at the wavelengths chosen for soot temperature measurements. For example, the digital camera using a lens aperture setting of f/16 could sequentially collect three images with the filter tuned to 650 nm and 850 nm for soot temperature measurement, and to 675 nm for soot volume fraction measurement. The Package can also be used for shadowgraph measurement by setting the lens aperture to f/5.6 with the filter at 675 nm.

The following figure illustrates the High Bit Depth/Multi-Spectral Imaging Diagnostic Package.

High Bit Depth/Multi-Spectral Imaging Diagnostic Package



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A.2.2.5.2 High Frame Rate/ High Resolution Diagnostics Package

Description

The HFR/HR Diagnostic Package consists of a telecentric optical system (Objective Optics and Relay Optics Modules), a trombone prism assembly (Focus Prism Module), a Pointing Mirror Module, a Filter Compensator Module, a high-resolution (1 mega-pixel) digital camera (Image Acquisition Module), and associated control electronics (DCM). The package will to accept the LCTF Module in place of the Filter Compensator for spectral filtering flexibility.

Specifications

Optical System

- Telecentric (no magnification change with object distance).
- 9 mm x 9 mm Instantaneous Field of View (IFOV) within a 46mm diameter total FOV truncated horizontally and vertically to 37mm.
- 20 lp/mm (25μ m) and 12 lp/mm (40μm) on axis resolution at 50% contrast modulation when operating in the high resolution mode and high frame rate modes respectively.
- Focus range: 30 mm autofocus capability.
- Instantaneous depth of field: 0.44mm.
- A liquid crystal tunable filter can be added.

Camera

- Imager is 1024 x 1024 pixel monochrome progressive scan frame transfer CCD.
- Digital 8 or 12-bit (when in binning mode) signal output, 8-bit when operated in the high resolution mode.
- Frame Rate: programmable for external sync, 7.5, 15, 30 or 60 fps and 110 fps when binning.
- Exposure time is user controllable. Shutter speed to 1/1000 second.
- Sub frame storage options are available in the acquisition system to reduce data storage requirements.

System

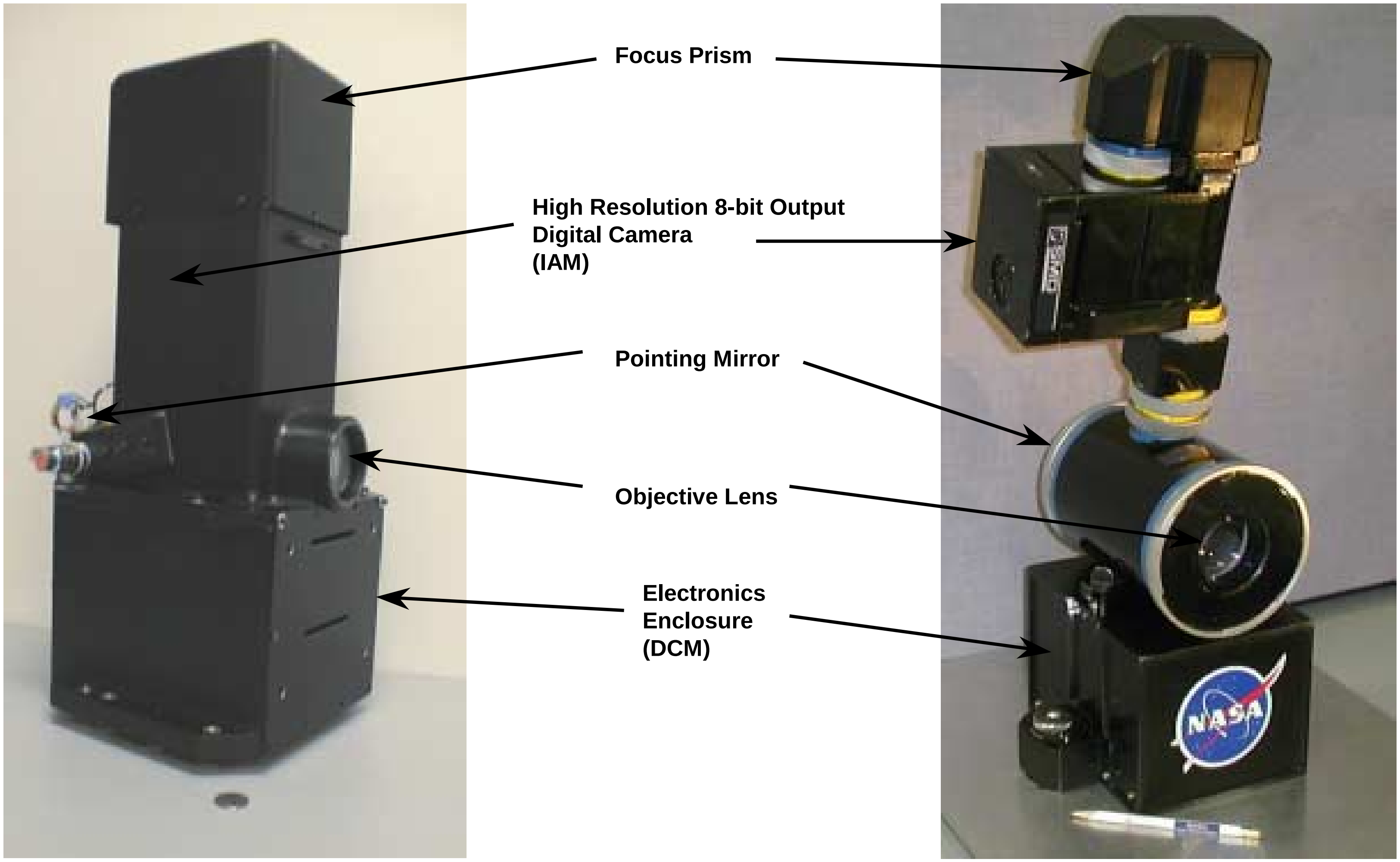
- The package is capable of automatically tracking an object within the total FOV while maintaining a sharp focus over a full object distance displacement range of 30 mm.
- 5 mm/s maximum tracking speed.
- 5 mm/s focusing speed.
- Programmable frame rate option allows for sequentially alternating from HFR to HR mode.
- Maximum package run time (8-bit output): 20 minutes (HFR mode) at 110 fps; 20 minutes (HR mode) at 30 fps.
- Event trigger capability.

Application Note:

The HFR/HR Package may be used in conjunction with the Illumination Package that provides object backlighting using a laser diode. The HFR/HR Package can also serve as a broad band imaging package. The addition of a liquid crystal tunable filter permits narrow band multispectral imaging including two or three wavelength pyrometric measurements for determination of soot temperature. When combined with a suitable external illumination source, the package can be used for Particle Image Velocimetry (PIV).

The following figure illustrates the High Frame Rate/High Resolution Diagnostic Package.

High Frame Rate / High Resolution Diagnostic Package



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A.2.2.5.3 Color Camera Diagnostic Package

Description

The color camera is a single chip frame transfer CCD with digital output and has numerous automatic and digitally controlled correction functions, such as gain control, electronic shutter speed, external synchronization, white balance control, and backlight correction via a RS-232C interface. Color is obtained with a color matrix filter on the CCD.

A 2x zoom lens is provided in the Relay Optics Module. This is coupled with two Objective Optics Modules to provide a range of field of view (FOV) and resolution choices. The PI can expand the package FOV with additional Objective Optics Modules to provide additional capabilities.

Maximum flexibility in the configuration of this package is available to permit operation from all diagnostic locations on the optics plate.

Specifications

Optical System

- Field of view: 90 to 350 mm square
- Resolution: 2.8 to 0.7 lp/mm at Nyquist limit (0.18 mm maximum resolution)
- 2x zoom lens, 2 objectives, auto iris

Camera

- 30 frames/sec frame rate
- 512 x 512 pixels
- Minimum illumination of 2 lux
- Gain control
- Auto and manual white balance control
- Backlight correction

System

- Maximum package run time (24-bit output): 27 minutes at 30 frames per second

Application Note:

The package can be used as a diagnostics data gathering system as well as for crew of ground checkout and verification of pre- and post- combustion events. Easy objective lens change out provides for other FOVs.

The following figure illustrates the Color Diagnostic Package concept.

Color Camera Module Concept

A.2.2.5.4 Low Light Level Package

Description

Two Diagnostic Packages are provided which produce images of events or objects at low radiance levels. These packages can be positioned on the Optics Bench to provide orthogonal views of an experiment. The two views have a spectral response overlap for wavelengths in the visible spectrum. A Low Light Level (LLL) package consists of a digital monochrome camera coupled to an intensifier with fast numerical aperture optics and provision for spectral filtering of the transmitted illumination. To provide maximum spectral range, including the OH emission line, one unit is equipped with a Gen II intensifier coupled to a lens system with high UV transmission characteristics, and the other contains a Gen III Ultra intensifier for sensitivity into the near IR.

Specifications

Optical System

- FOV - UV: 42 and 100 mm square
- FOV - IR: 40 to 160 mm square
- 2X zoom capability on the LLL-IR package. Two objective lenses with each package.
- Automatic iris control
- Automatic focus
- Resolution: At wide field UV: 2.6 Ip/mm (0.2 mm)
  At wide field IR: 1.6 Ip/mm (0.3 mm)
  At narrow field: 6.1 Ip/mm (0.08 mm)

Camera

- Digital Output: 8 bit depth
- Manually inserted filters provided:
  OH: 310 nm with a 10 nm FWHM bandwidth filter
- Spectral range with no filter @ half maximum and @ 10% points:
  UV: 280 to 700 nm and 200 to 800 nm
  IR: 500 to 875 nm and 400 to 900 nm
- Sensitivity
  UV: 6 x 10E-9 ft-candles
  IR: 4.4 x 10E-9 ft-candles
- Intensifiers
  UV: industry standard Gen II
  IR: industry standard Gen III Ultra
- Automatic gain
- 60 frames per second

System

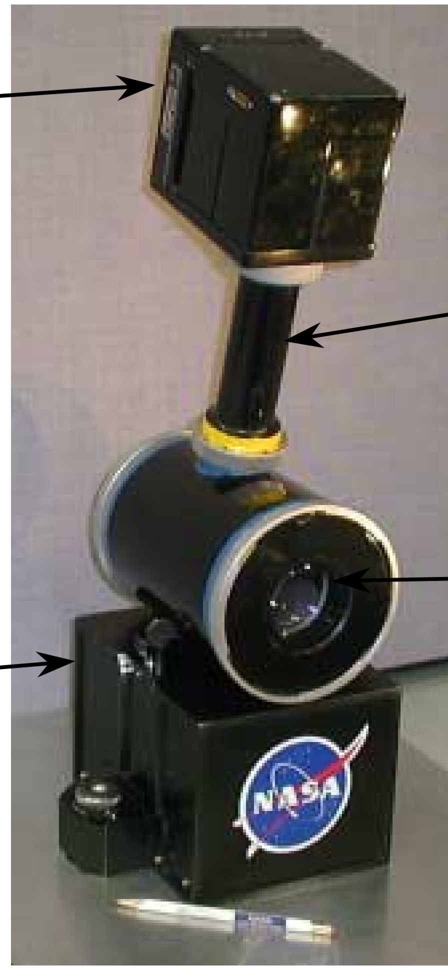
- Intensifier gain control programmable
- Adjustable programmable aperture
- 20 minutes of run time at 30 fps.

Application Note:

The packages can be programmed individually to acquire images at independent gain settings. The investigator has the option of setting the LLL-IR FOV to match the LLL-UV FOV. The combustion event can be recorded in matching or different spectral regions that are defined by investigator-provided filters.

The following figure illustrates the Low Light Level Diagnostic Package concept.

Low Light Level Packages - Module Concept



A.2.2.5.5 Mid-IR Camera Package

Description

A Mid-Infrared Camera Package is provided which produces images of events or objects emitting in the range of 1000 to 5000 nm. The package has provision for manual insertion of filters into the optical path. The flange mount interface is used so that alternative objective optics can be installed. The camera detector is Sterling cycle cooled (no cryogenic liquids are used). Alternative chamber windows (investigator provided) may be installed along with the package if unique spectral transmission characteristics are required.

Specifications

Optical System

- 183 mm x 138 mm FOV
- Resolution: 0.9 Ip/mm
- Depth of Field: 25 mm at f/1.2

Camera

- Spectral Range: 1000-5000 nm
- Focal Plane Array detector
- 320 x 244 pixel elements
- Temp. Measurement Accuracy: $\pm$2% of reading or 2^{o} C
- Noise Equivalent Temp. Difference (NETD): <0.1K@ 30°C
- Temperature Measurement Range:
  -10^{o} C to 450^{o} C (up to 1500 C if filter is used)
- Emissivity Range: 0.1 to 1
- Maximum Frame Rate: 60 non-interlaced frames per second
- Dynamic Range: 12-bit
- Digital Output
- Integration Time: 0.001 to 0.016 sec
- Gain, level (offset), integration time and emissivity range are user selectable; also have an autogain control override option

System

- Maximum run time: 200 minutes when operating at 60 fps
- Minimum Resolvable Temperature Difference (MRTD): 0.2°C @ 0.9 Ip/mm
- Automatic and investigator defined calibration options: Typically 2 point correction is applied; 3 or 4 point correction will be optional

Application Note:

The Mid-IR Camera Package can be programmed to acquire images at PI selectable gain settings. This permits the investigator to override autogain if necessary to permit recording of faint emissions or absorption lines in the presence of brighter objects or to keep a bright, small object out of saturation. The package design permits installation of an investigator-provided filter wheel at a defined interface in the optical system.

The following figure illustrates the Mid IR Diagnostic Package concept.

Mid IR Package Module Concept

A.2.2.5.6 Illumination Package

Description

The Illumination Package consists of a collimated optical system with a software controlled selector mirror and three ports with FC or ST style connectors for optical fiber coupling to modular illumination sources for operational flexibility. Two illumination sources are provided with the package. One of the illumination sources is a current stabilized Tungsten Halogen lamp that can be used for radiometric calibration. The other source is a laser diode which can be used to provide monochromatic background illumination.

Specifications

Optical System

- Collimated
- 80 mm diameter
- Divergence: 7.6 milliradians

Tungsten Halogen Source (Calibration Lamp)

- Irradiance: 0.6 lumens/mm^2
- Illumination Field Uniformity: 70%
- Color Temperature: 3000K
- Stability: 2%

Laser Diode Source

- Coupled Power. 5 mw minimum (may be programmable)
- Illumination Field Uniformity: 78%
- Peak Wavelength: Between 660 and 690 nm
- Spectral Bandwidth: 7 nm maximum at 50% points

Application Note:

The Illumination Package can be used with the laser diode source selected to provide a uniform illumination background for soot absorption measurements in soot volume fraction applications. The LD may be used as a non-coherent illumination source if operated below the lasing threshold. For example, illumination output is sufficient to provide saturation signal levels with HiBMs at 30 fps without binning at a numerical aperture of 0.01. This illumination source can be synchronized with an imaging system if required by the application.

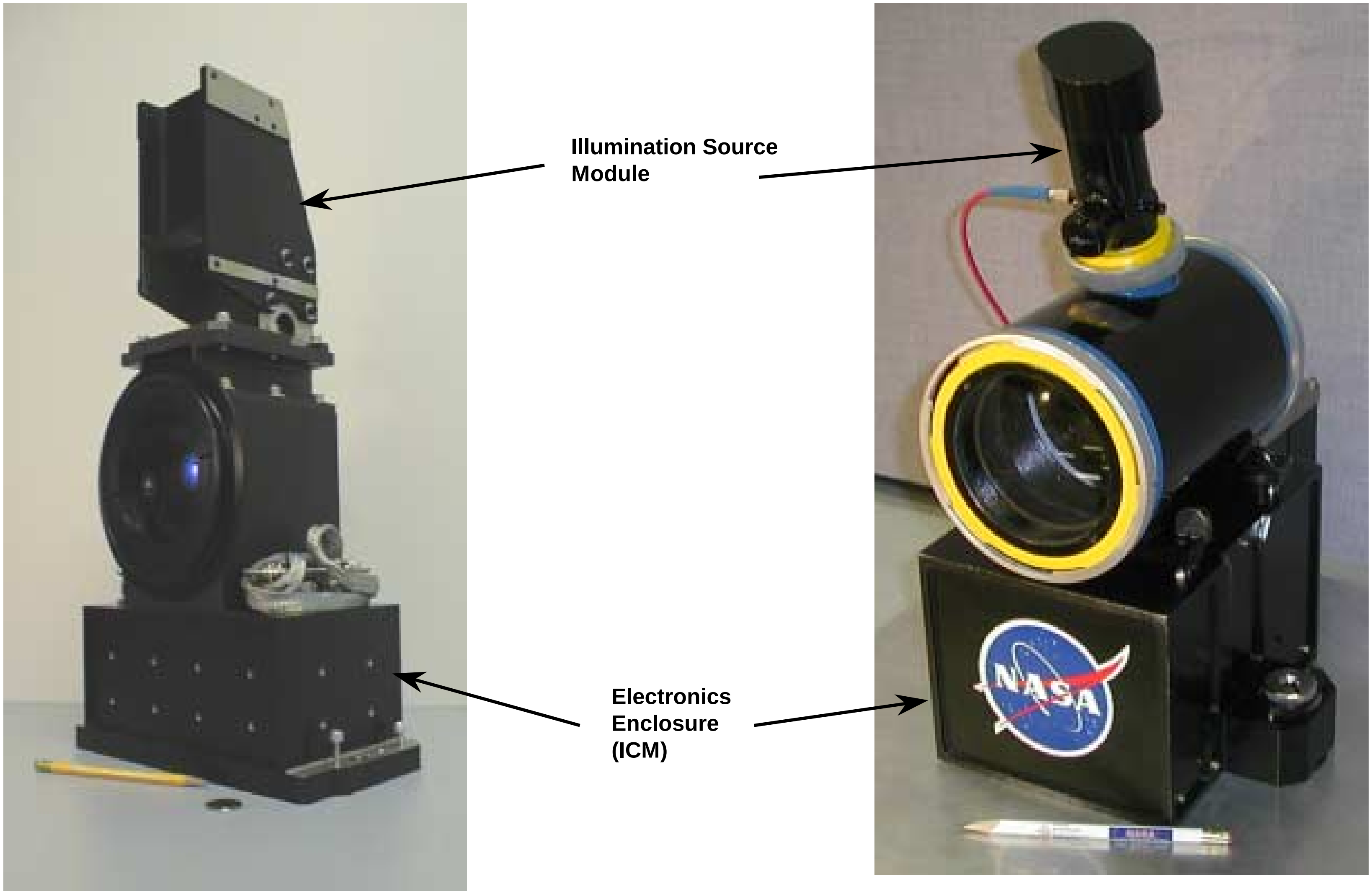
The laser diode can also be used as the background illumination source for shadowgraph measurements with the HiBMs Package or for droplet size measurement with the HFR/HR Package.

The modular design supports future growth considerations. For example the laser diode illumination path could be used for interferometric or Schlieren applications. With the addition of cylindrical power by changing the Objective Optics Module, a light sheet would be formed for use in Particle Image Velocimetry.

Other fiber coupled illumination sources could be inserted by mating with the FC or ST connectors.

The following figure illustrates the Illumination Diagnostic Package.

Illumination Package



Breadboard

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A.2.2.5.7 Diagnostic Control Module

Description

A Diagnostic Control Module (DCM) provides the control, power, cooling and mechanical alignment interfaces between the remainder of the modules in a diagnostic package and the Optics Plate. These modules are of a common basic design for all of the diagnostics with the exception of the Illumination Package that interfaces to an Illumination Control Module that has external interfaces that are identical to a DCM but different internal design characteristics. The module is attached to the Optics Plate using a removable Latch Handle that operates the attachment mechanisms. One handle will support all of the DCMs in the facility. A duct mates with the cooling port at the UML site. Direct access to the UML cooling port is provided at the top of the DCM. Alignment pins provide optical system positional repeatability on the Optics Plate. The mechanical interface to the rest of the modules is a kinematic mount that transfers optical system alignment precision from the Optics Plate without introducing stress loads. An optical fiber feed-through handles data coming from the IAMs. There is also provision for conducting analog video (RS170) to the UML.

Specifications

Electrical

- Motor Drive Current Limit:

  Servo: 1.5 amperes maximum

  Stepper: 0.9 amperes maximum (0.25 amps per winding)
- Camera Voltage: 28 volts
- Camera Current Limit: 5 amperes
- Optics Plate Interface: blind mate 2-bay ARINC connector
- Module interfaces:
  Camera/motors: 100 pin miniature Airborn connector
  Filter: 31 pin miniature Airborn connector

Mechanical

- Height: 133 mm
- Angular alignment accuracy: TBD
- Lateral position accuracy: TBD

System

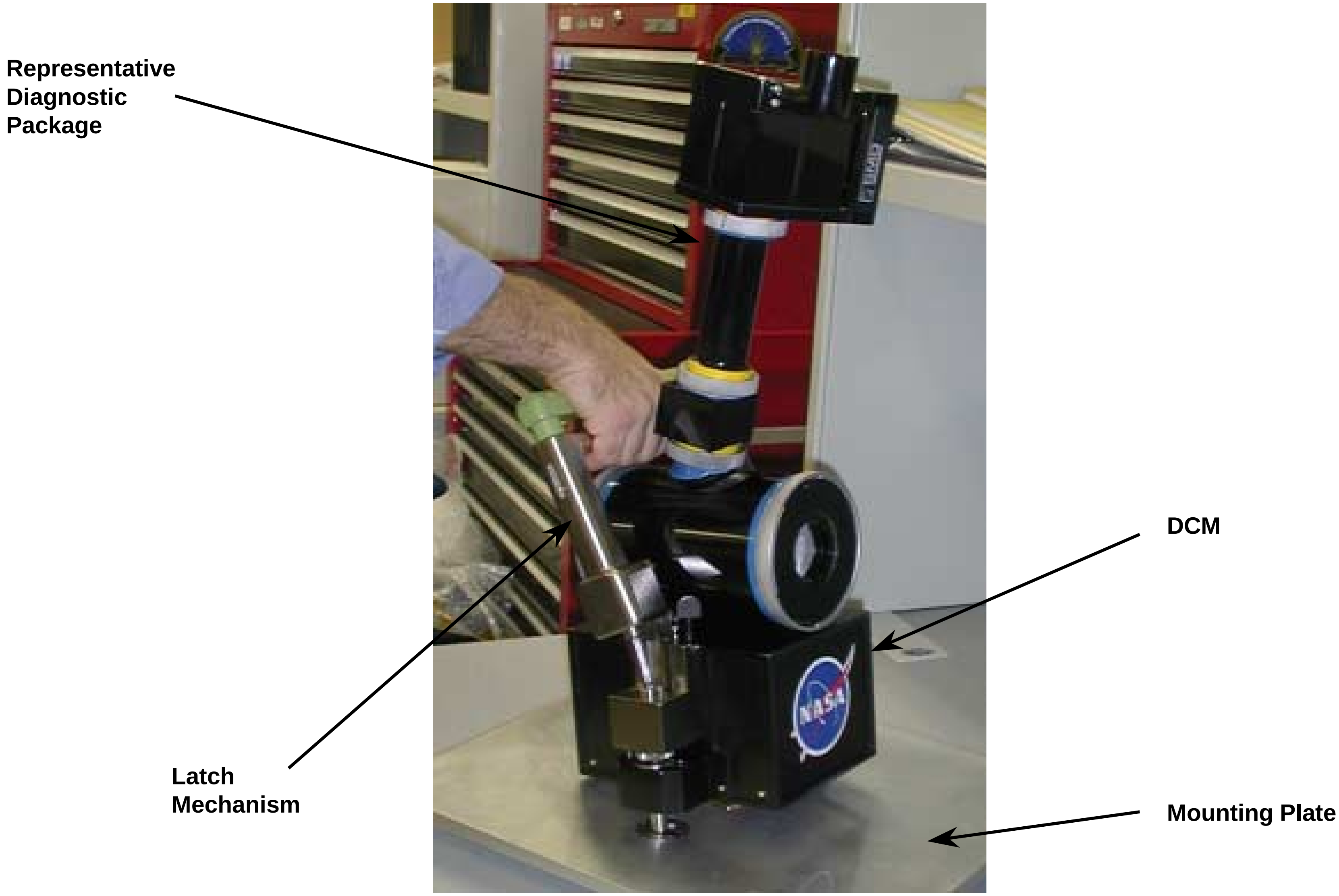
- Cooling capacity for external devices: 60W at a pressure drop of 0.200 in. H2O
- Two CAN Bus connections are provided. One is dedicated to control of the DCM. The other is routed to the 100 pin Airborn connector.
- RS232 communication is provided at the output for camera package contol.

Application Note:

A maximum of four servo motors or four stepper motors or combinations of stepper/servo motors in pairs can be controlled simultaneously. Maximum total drive current is limited to 2 amperes.

The following figure illustrates the Diagnostic Control Module and Latch.

Diagnostic Control Module and Latch Mechanism



A.2.2.6 Gas Interface Subsystem

Description

The Gas Interface Subsystems (GIS) provides interfaces for science packages to access ISS provided Gaseous Nitrogen (GN_2), Vacuum Exhaust (VES) services. The CIR Gas Interface Subsystems Schematic Diagram is shown in Figure 4.33. Access to the GN_2 and VES services will be via fluid system quick disconnects (QD's). An interface will be located on the left side of the rack in front of the Optics Bench. Flexible hoses will be used to connect the GN_2 and VES subsystems to the FOMA.

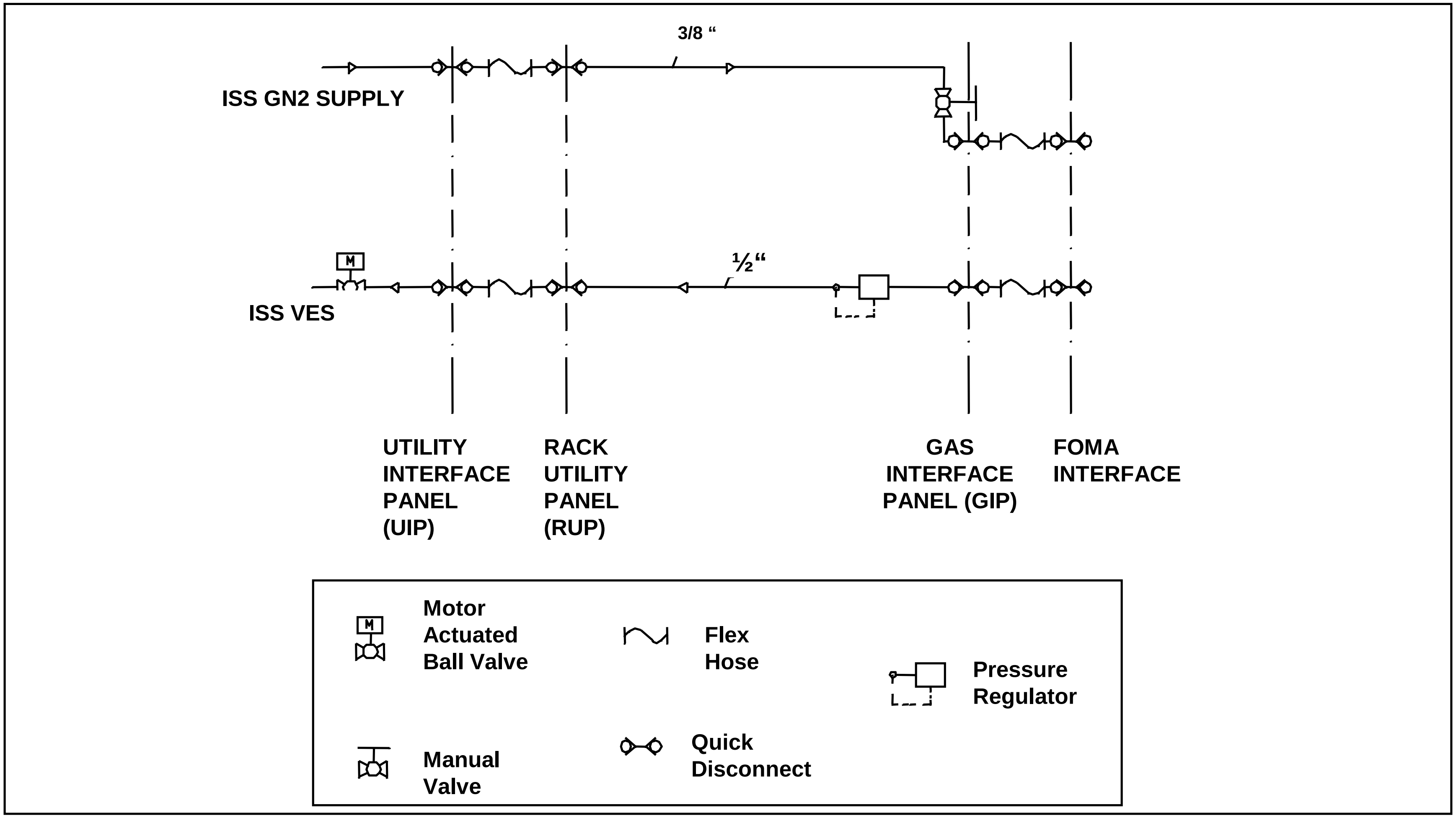
Features

- A downstream vent valve on the Gas Interface Panel (GIP) shall provide a positive shutoff for the GN_2 supply and prevent the quick disconnect from being mated in a pressurized state.
- A pressure regulator is located in the GIS VES to prevent overpressurization of the ISS VES. The FOMA system also contains hardware and instrumentation to prevent overpressurization.
- A motorized shutoff valve is provided by ISS for the VES.
- Self-sealing quick disconnect halves with virtually no leakage or air inclusion during mate or de-mate operation shall be used. In the unmated position, pressure caps or plugs shall be installed to provide a redundant seal and protection of surfaces.
- No pressure monitoring capability is incorporated in these subsystems systems. The pressure monitoring capability for the GN_2 and VES is housed in the CIR FOMA system.
- The GN_2 subsystem provides up to 5.43 kg/hr and a pressure range of 517 to 827 kPa. The mass flow rate is regulated by the FOMA system.
- The VES provides a throughput of $1.3x10^{-3}$ torr*liter*s at a pressure of $1x10^{-3}$ torr.

A quick disconnect on the Rack Utility Panel (RUP) for VRS connection is **TBD**.

The following figure illustrates the Gas Interface Subsystem mechanical schematic.

Gas Interface Subsystem Schematic



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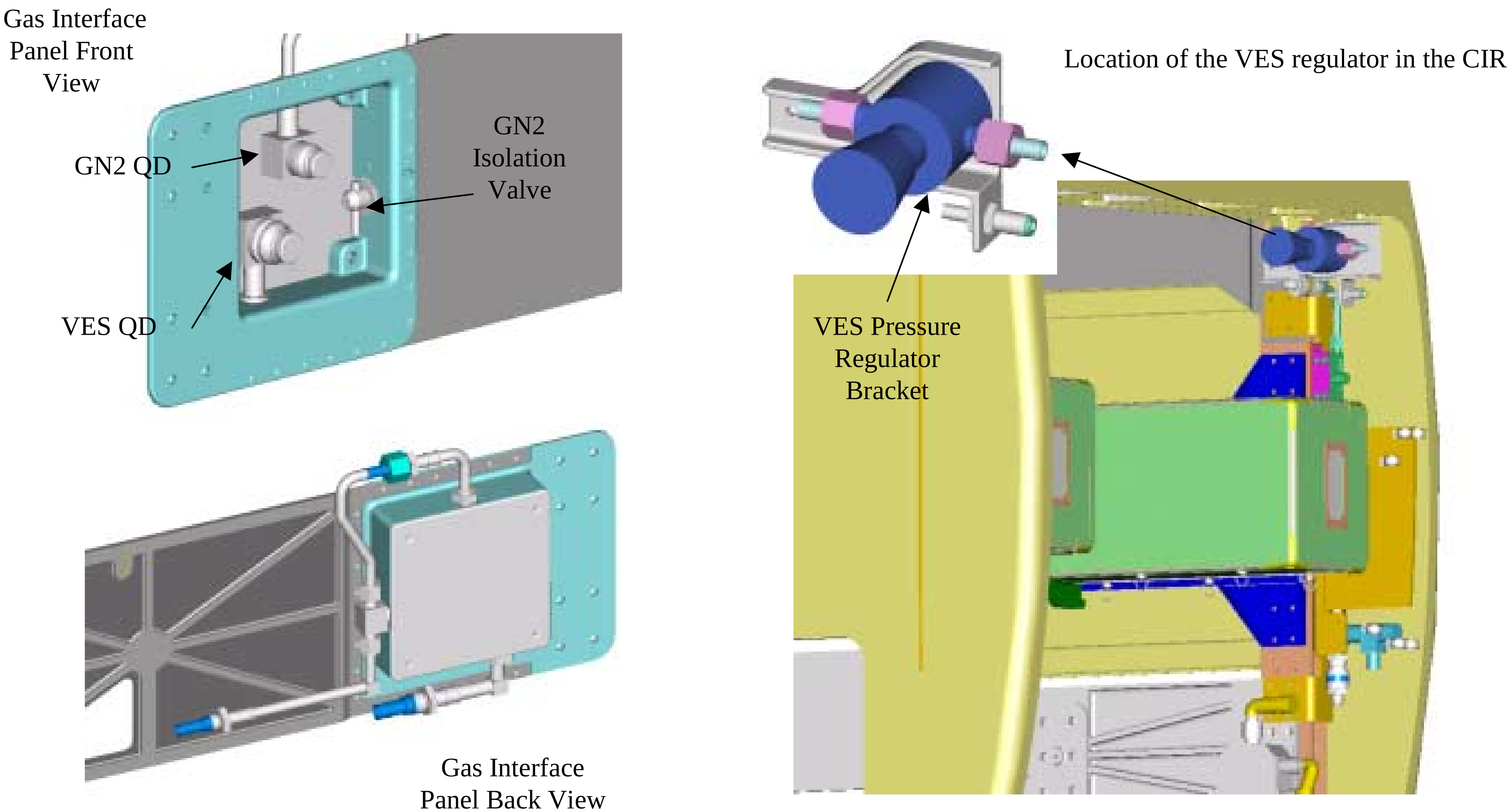
The following figure illustrates the Gas Interface System interconnection.

Gas Interface System Interconnection



A.2.2.7 CIR Avionics Subsystem

A.2.2.7.1 Major Packages

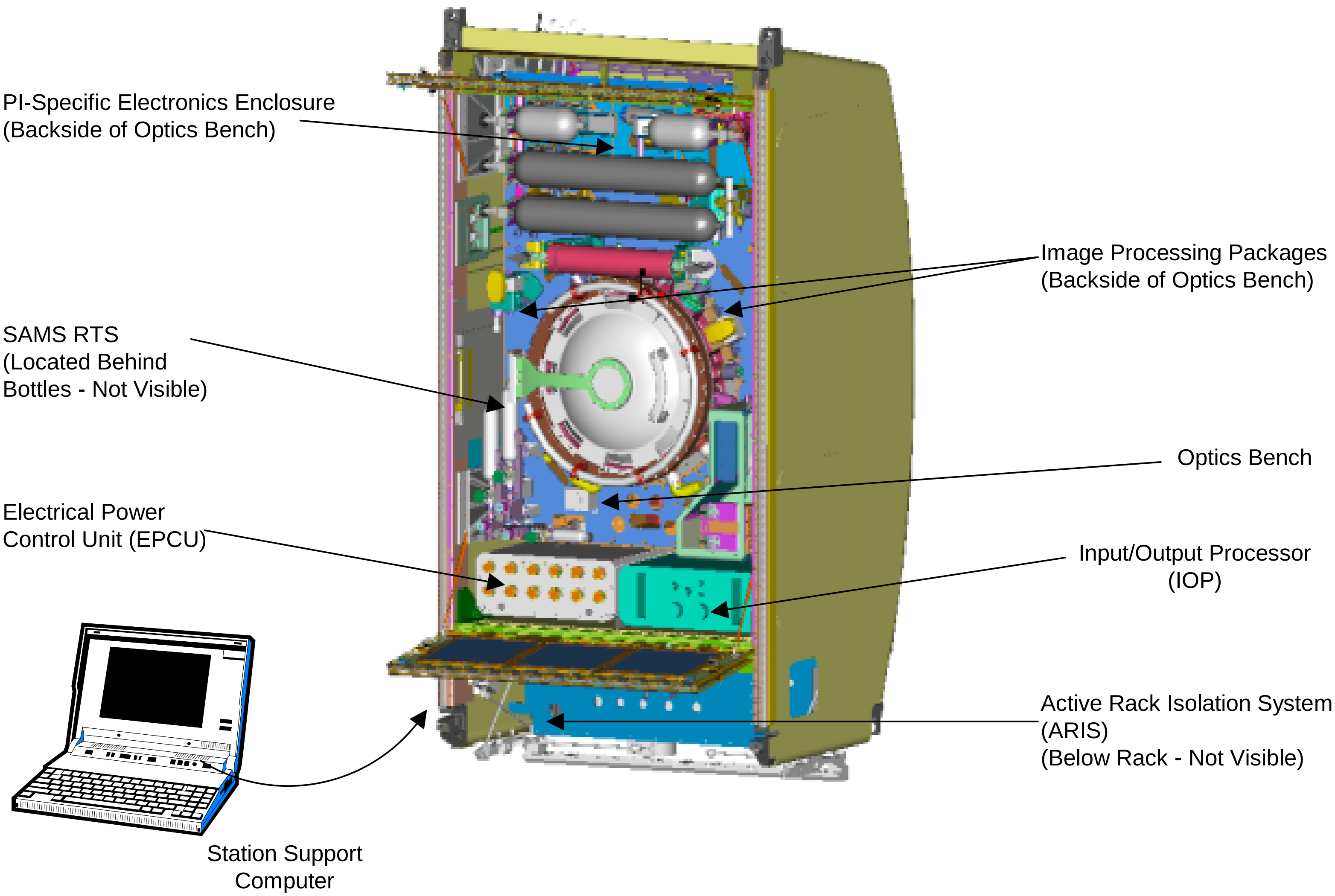
The CIR major avionics packages are:

- Input/Output Package (IOP)
- Electrical Power Control Unit (EPCU)
- Two Image Processing Packages (IPPs)
  (Each containing 2 IPSUs)
- FOMA Control Unit (FCU)
- Station Support Computer (SCC)
- PI Specific Electronics Box
  (currently being defined to hold some TBD set of standard avionics services for the CIR).

Only the FCU is described in the following sections. For more description of the other packages please refer to the common hardware description sections above.

The following figure illustrates the locations of the CIR Avionics Subsystems.

CIR Avionics Subsystems



A.2.2.7.2 FOMA CONTROL UNIT (FCU)

Description

The FCU performs command processing, control, data processing, health and status monitoring associated with the FOMA. The FCU incorporates the following features:

- 6U VME Bus Architecture
- CAN Bus Interface
- Power Supplies and Filters
- Hard Disk Drive

Interfaces

The FCU provides the following interfaces:

- 100baseT Ethernet – Facility Ethernet interface for data transmission to ISS via the CIR IOP.
- CAN Bus - Interface with IOP for redundant valve and pressure switch status monitoring.
- Analog Inputs – For interfacing with the FOMA pressure transducers, thermistors, mass flow controllers, and voltage monitoring.
- Analog Outputs – For commanding setpoints of the mass flow controllers.
- Discrete Input/Outputs – for detecting switch positions, activation of valves, etc.

The physical construction of the CIR FCU consists of one 7-slot VME backplane located on the Optics Bench. This VME backplane supports the following:

- Single Board Computer (SBC)
- Ethernet Interfaces
- 3 VME carrier boards that support the Industry Pack form factor for I/O boards.
- 2 Solenoid driver boards.
- One, SCSI-2, 814 Mbyte VME form factor hard disk drive

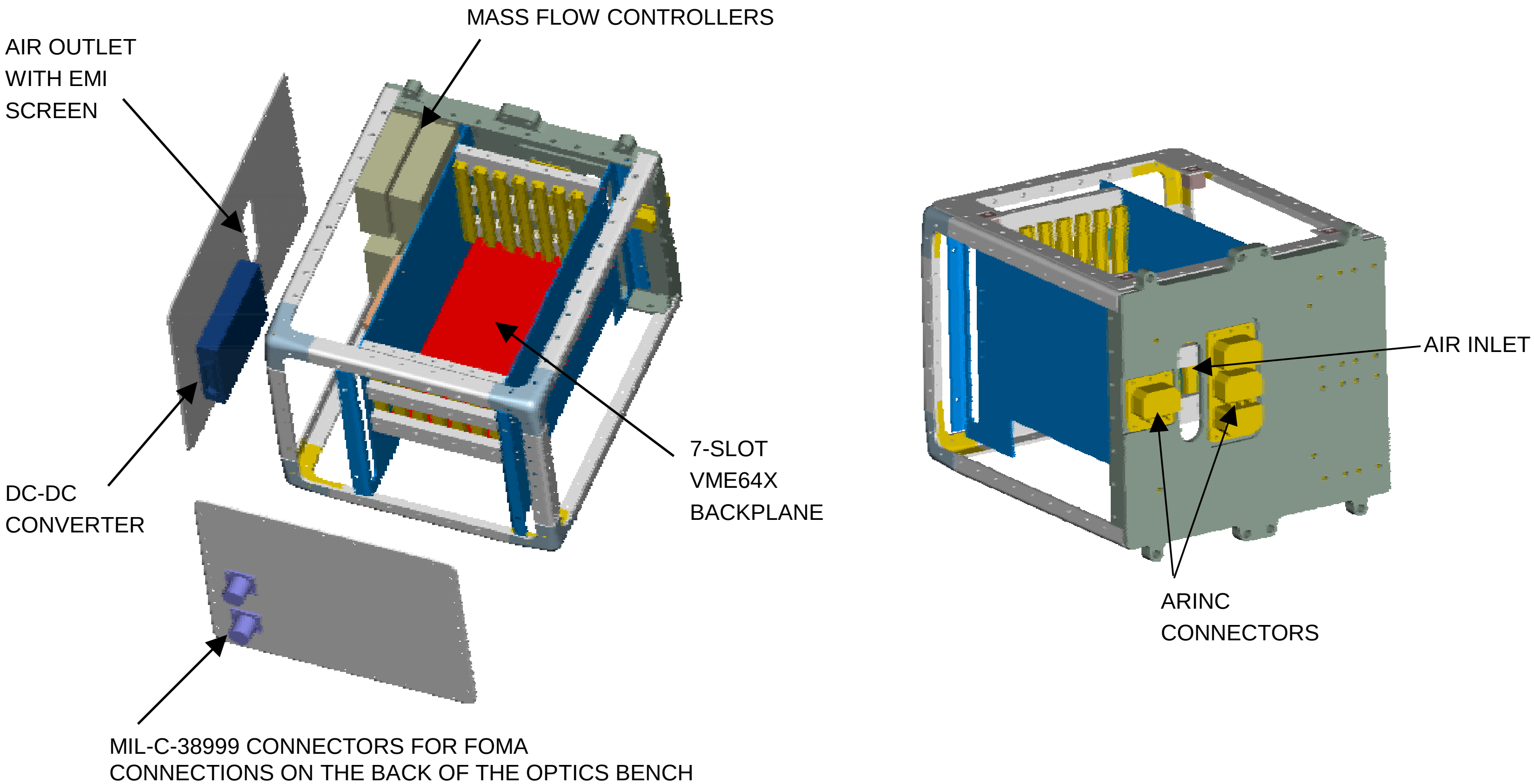
FCU Power Requirements

	Power Requirements (Watts)						
+5V	+12 V	-12 V	+15 V (GC)	+15 V	-15 V	+24 V	Total
33.5	2.9	4.1	0.0	0.0	0.0	11.3	51.8
17.0	0.0	0.0	0.0	0.0	0.0	0.0	17.0
7.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0
0.0	0.0	0.0	0.0	7.5	15.0	0.0	22.5
0.0	0.0	0.0	29.0	0.0	0.0	0.0	29
57.5	2.9	4.1	29.0	7.5	15.0	11.3	127.3
Including DC-DC Converter Losses (75% Efficient)							169.7
Adding Margin (10%)							186.7

Note: These requirements do not include the power required to operate FOMA hardware such as solenoid valves.

The following figure illustrates the FOMA Control Unit.

FOMA Control Unit (FCU)



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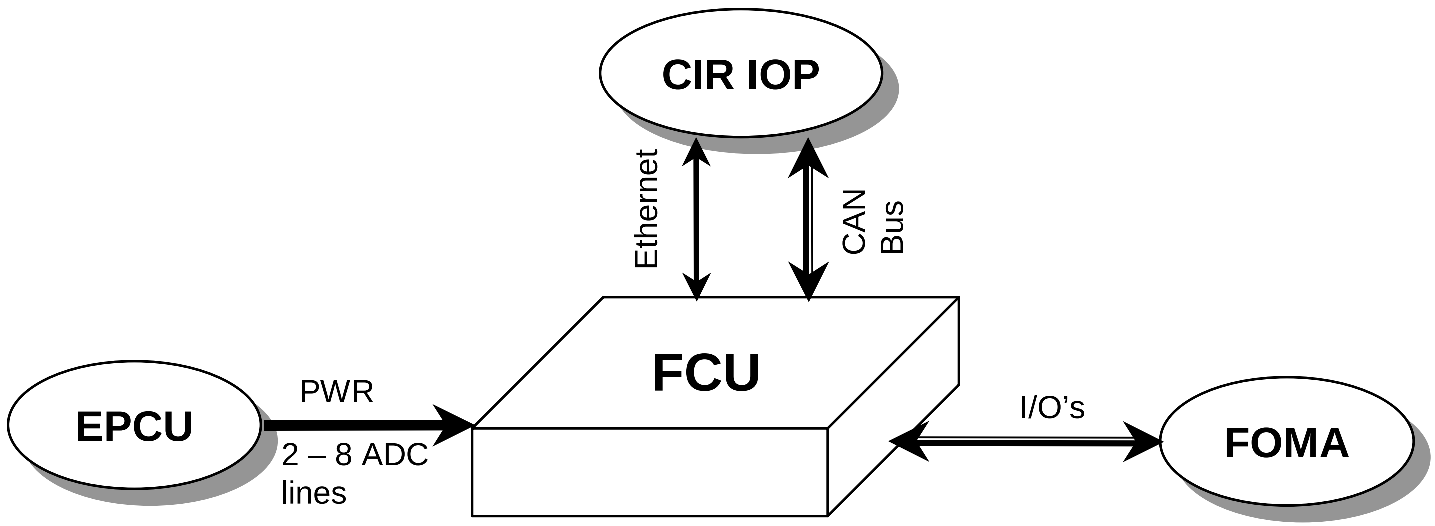
The following figure illustrates the FCU external interfaces.

FCU - External Interfaces



A.2.2.7.3 Risk Mitigation for Ionizing Radiation

Design Guidelines

- Leverage the opportunities presented by COTS electronics for minimizing power consumption, minimizing mass, minimizing costs, and maximizing performance to ultimately provide the greatest science return on investment.
- On-orbit sparing will be provided for all avionics ORUs.

Risk Mitigation Approach

- Work with GSFC Radiation Effects Analysis Team to complete an initial SINGLE EVENT EFFECT CRITICALITY ANALYSIS for the FCF.
- Define and derive functional requirements based upon SEECA, SSP 57000, FCF Science objectives, and expected radiation environment (per SSP 30512).
- Maintain up-to-date knowledge of know problem-areas based upon past flight projects and ground testing:
- Leverage experiences of Biotech, EXPRESS, SAMPEX, Hubble, TOPEX, Cassini.
- Periodically review information contained in GSFC's Radiation Effects and Analysis home page, JPL's RADATA database, IEEE Transactions on Nuclear Science, etc.
- Perform detailed design and identify appropriate mix of risk mitigation strategies
- Educated selection of devices such as solid state memory, microprocessors, optocouplers, fiber optic data busses, EEPROMs.
- Discuss requirements with manufacturers and review radiation performance data.

Risk mitigation strategies include:

- Error Detection and Correction (EDAC) code
- Rad-hardened hardware
- Rad-tolerant hardware
- Two-step commanding
- Duplication of critical flight code
- Perform test at subsystem level with SEE specialists from GSFC and test facilities.

NOTE: The Fluids and Combustion Facility Single Event Effect (SEE) Risk Mitigation Plan (DRAFT 4/14/98) may be referenced for additional information.

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A.2.3 CIR METRICS

Mass Summary

The following figure details the estimated mass of each CIR subsystem. The table lists all of the subsystems that will be needed for on-orbit operation as well as the subsystems that will be installed for launch. Additional information can be found in the *FCF Mass Properties Report* (FCF-RPT-0061).

All of the diagnostics and image processing packages will be stowed in foam lined re-supply lockers for launch. This will minimize environmental testing of the packages that can reduce development costs and enable the project to use COTS for many of these components. To minimize crew time for the installment and reconfiguration, these components have an integral quick latch mechanism that allows for easy installation and removal.

The following figure summarizes the CIR mass by assembly.

FCF CIR Mass Estimates for Launch and On-Orbit Configurations

	Assembly	Base Estimate (Kg)	Percent of Total	Installed During Launch ?	Installed During Operation?
CIR Unique Hardware	Chamber - Chamber Assembly	138.85	17.99%	Y	Y
	Diagnostics - Color Camera	9.40	1.22%	**N**	Y
	Diagnostics - UV Camera	11.40	1.48%	**N**	Y
	Diagnostics - HiBMS Camera	9.14	1.18%	**N**	Y
	Diagnostics - Mid-IR Camera	9.77	1.27%	**N**	Y
	Diagnostics - HFR/HR Camera	8.83	1.14%	**N**	Y
	Diagnostics - Illumination	8.62	1.12%	**N**	Y
	Diagnostics - IPP A	18.16	2.35%	**N**	Y
	FOMA	78.70	10.19%	Y	Y
	FOMA - FCU	14.42	1.87%	**N**	Y
	FOMA - Gas Chromatograph Launch Mass	9.39	1.22%	Y	Y
	FOMA - Gas Chromatograph Additional On-Orbit Mass	11.49	1.49%	**N**	Y
	FOMA - Bottle (3.8L)	10.07	1.30%	**N**	Y
	FOMA - Bottle (3.8L)	10.07	1.30%	**N**	Y
	FOMA - Bottle (3.8L)	10.07	1.30%	**N**	Y
	FOMA - Absorptive Filter (Large)	4.70	0.61%	**N**	Y
	Optics Bench - Optics Bench Assembly	99.87	12.94%	Y	Y
Common Systems	Diagnostics - IPSU's (2)	15.64	2.03%	Y	Y
	Diagnostics - DCMs (6)	13.02	1.69%	**N**	Y
	Rack -Doors Assembly	25.00	3.24%	Y	Y
	Optics Bench - Pins	5.95	0.77%	Y	Y
	Rack - Misc. Rack Structures	10.57	1.37%	Y	Y
	IOP - I/O Processor	24.70	3.20%	Y	Y
	IOP - I/O Processor Harddrives	4.44	0.58%	**N**	Y
	Optics Bench - Slides	48.54	6.29%	Y	Y
	Diagnostics - Removable Latch	2.57	0.33%	**N**	Y
	ECS - Water Distribution & Control Assy	32.54	4.22%	Y	Y
	ECS - Accumulator Assembly (removed on orbit)	1.80	0.23%	Y	**N**
	ECS - Air Thermal Control Assembly	44.64	5.78%	Y	Y
	ECS - Gas Interface Assy	16.23	2.10%	Y	Y
	ECS - Fire Detection & Supression Assy	2.47	0.32%	Y	Y
	EA - Service Umbilical Set & ESSA Switch	6.48	0.84%	Y	Y
PI	Chamber - Chamber Insert Assembly	40.00	5.18%	**N**	Y
	Diagnostics - PI-Specific Electronics	14.42	1.87%	**N**	Y
GFE	ARIS - Launch Condition*	61.06	7.91%	Y	Y
	ARIS - Additional On-Orbit Mass*	14.45	1.87%	**N**	Y
	EPS - Electrical Power Control Unit	48.53	6.29%	Y	Y
	EPS - EPCU Umbilicals	2.84	0.37%	Y	Y
	EPS - RMSA Switch	0.64	0.08%	Y	Y
	SAMS - SAMS Subsystem	1.23	0.16%	Y	Y
	Rack - Rack Assembly	111.90	14.50%	Y	Y
	Rack - Rack-to-Station I/F Umbilical Set	10.66	1.38%	**N**	Y
	Management Reserve				
	LAUNCH CONFIGURATION BASE MASS	**771.93**			
	OPERATNG CONFIGURATION BASE MASS	**1021.46**			

CIR Power Estimates

Power estimates for the CIR subsystems are included in the Power Estimate Table. The estimates include the typical and maximum power consumed by each subsystem for both the 28 and 120 VDC supplies.

The following table details the CIR subsystem power estimates.

CIR Subsystems – Maximum Power Estimates

CIR Hardware Assembly				Typical @ 28VDC (Watts)	Maximum @ 28VDC (Watts)	Typical @ 120VDC (Watts)	Maximum @ 120VDC (Watts)
				Power Estimates			
Core Elements			IOP	148.0	148.0	0.0	0.0
			IPSU	136.0	136.0	0.0	0.0
			SSC	39.2	39.2	0.0	0.0
			SAMS	2.0	2.0	0.0	0.0
			ARIS	0.0	0.0	123.0	123.0
Combustion Elements	Science Diagnostic Packages	Avionics	Diagnostic Control Module	48.0	48.0	0.0	0.0
		Imaging Packages	Image Acquisition Module	37.0	37.0	0.0	0.0
			Illumination Package	25.0	25.0	0.0	0.0
			FCU/FOMA	137.0	137.0	0.0	0.0
			EEU	60.0	60.0	0.0	0.0
			FDSS	0.0	0.0	3.0	3.0
		Cooling	ATCS (Fans)	150.0	150.0	0.0	0.0
			WTCS WFCA	18.0	18.0	0.0	0.0
		Specific Science Packages	Science PI Box	200.0	222.0	0	0
			Science Chamber	100.0	444.0	0.0	0.0
			Science (Chamber 120 VDC)	0.0	0.0	0.0	1440.0
		Subtotal		1100.2	1466.2	126.0	1566.0
		Cable Losses(2%)		22.0	29.3	2.5	31.3
		Subtotal		1122.2	1495.5	128.5	1597.3

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Section 3 Utilization and Operations

A.3 UTILIZATION AND OPERATIONS

A.3.1 On-Orbit Operations

The physical operation of the CIR on-orbit can be separated into roughly two nominal configurations.

- Nominal PI Setup Scenario
- Nominal PI Operational Scenario

Each scenario has hardware operations that are unique to that scenario as well as scenarios that are common to both.

A.3.1.1 Nominal PI Setup Scenario

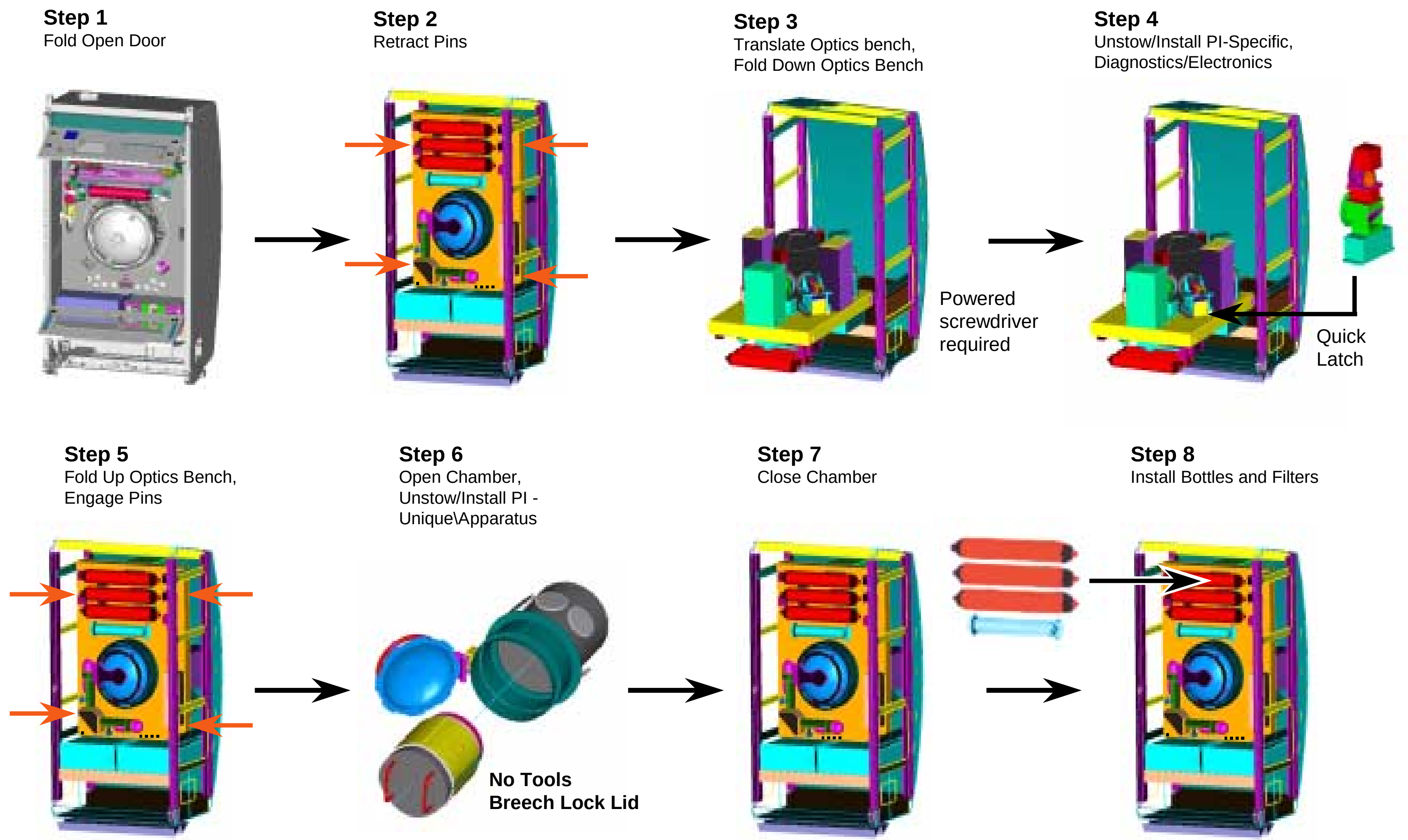
In order for an experiment to be executed in the CIR it must first be installed. This begins with the rack door being opened and the optics Bench pins being retracted. When completed the crew, using the powered screwdriver will translate the Optics Bench out of the rack and fold the Bench down.

Once the Bench is folded down the CIR provided or PI specific diagnostics can be installed along with any unique electronics. Once the equipment is installed the Optics Bench will be folded up and translated into the rack.

With the Optics Bench in the rack, the crew will open the Chamber and install the PI Specific Hardware. No tools are required to install the new equipment. With the PI Specific Hardware installed the Chamber is closed and new gas bottles and exhaust filters will be installed.

The following page describes a normal PI set-up scenario for the CIR.

Normal PI Setup Scenario



A.3.1.2 Nominal PI Operational Scenario

After the PI specific hardware is installed in the CIR, experiment operations can begin.

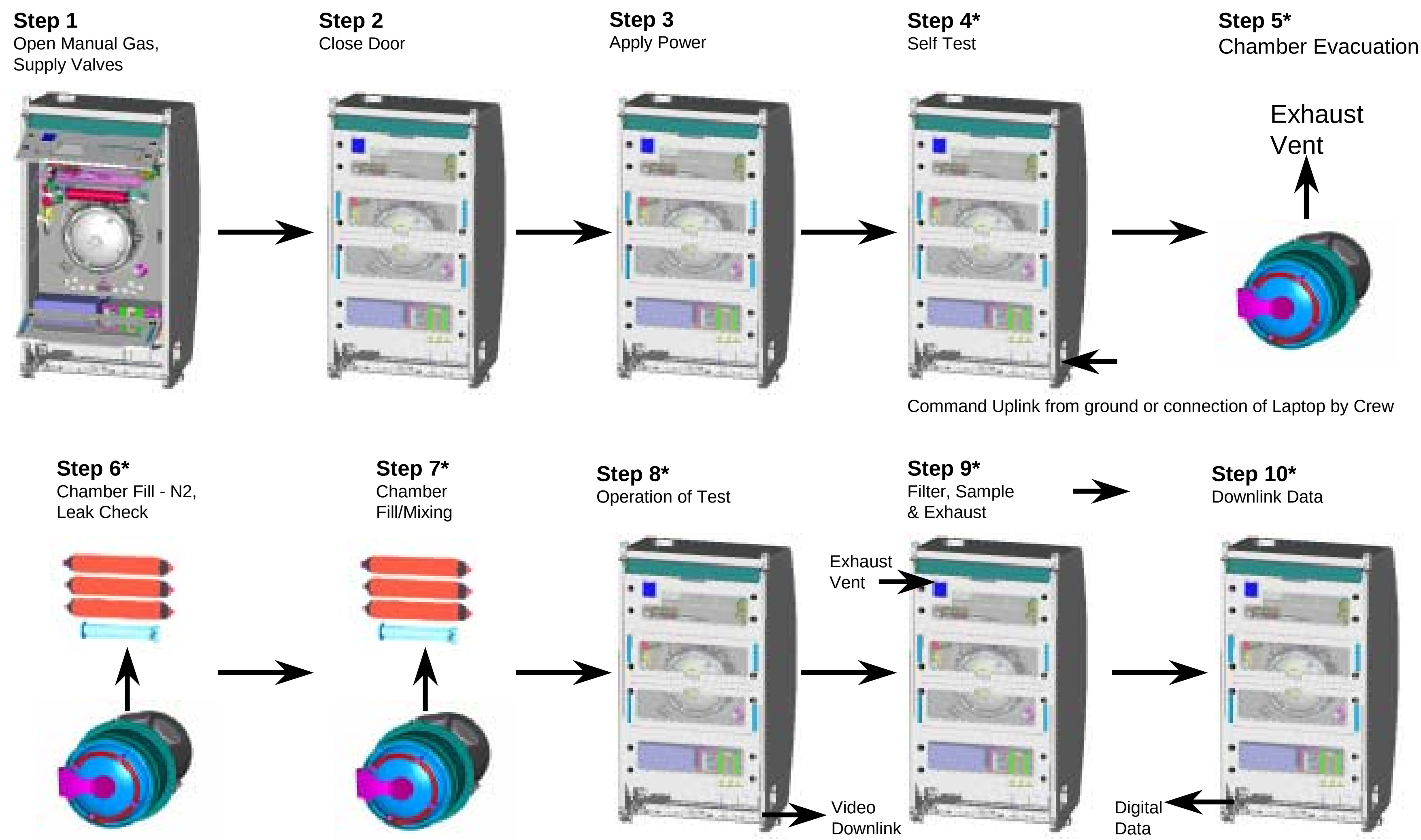
The execution of a test point or set of test points begins with the crew opening the rack door to open the required gas supply manual valves. The door is then closed and power is enabled at the rack interface. When the power is enabled the CIR computer initializes the ATCU starts up and the CIR undergoes a self-test. Required commands can be sent to the CIR from the ground operators or by the crew using the laptop computer

When the self-test is completed the Chamber is evacuated and filled with nitrogen to test for leaks. When the leak check is finished the nitrogen will be vented and the FOMA will be commanded to fill the chamber with the desired mix of gases. When the chamber contents meet the required levels, the test point can be run and data downlinked.

After the test is completed the chamber contents will be analyzed and processed in order to vent to space. While this is taking place the high-resolution video images will be downlinked for analysis.

The following page illustrates how the CIR will conduct a test point.

Nominal PI Operations Scenario



A.3.2 CIR RECONFIGURATION SCENARIOS

Several different types of operations will nominally be performed during the operations of the CIR before and after the SAR is deployed.

Front Panel Operations

There are several operations that take advantage of the ability to access equipment from the rack face requiring a minimum of tools and crew time. With the front panel open access is provided to the combustion chamber, gas bottles, EVP filters, and the IOP and EPCU.

EMS removal and installation

Each PI will require his own experiment mounting structure for supporting his equipment within the combustion chamber. The CIR allows this hardware to be changed out by simply opening the chamber (after verifying it is not pressurized) disconnecting the instrumentation and removing the EMS. A new experiment can be installed by simply inserting a new EMS into the chamber and reconnecting the instrumentation.

Chamber Window replacement

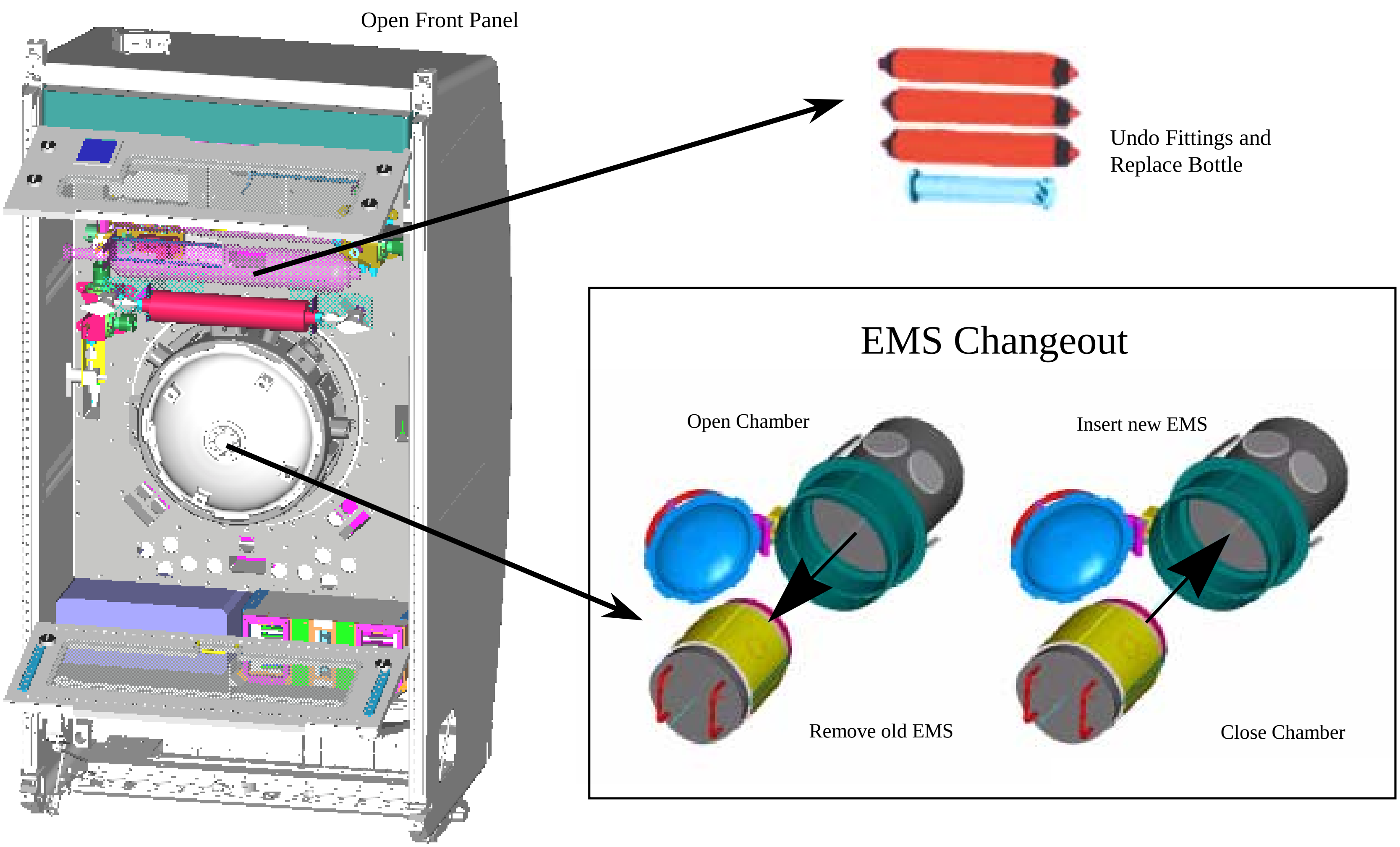
The combustion chamber allows up to 8 diagnostics to view the interior through special viewports. Over time it is expected that new windows with new optical properties will need to be installed in the chamber. This can be done with no special tools by removing the EMS, selecting the desired window and folding out the built in handle. The window can then be unscrewed from the chamber and replaced with a new one with the required properties.

Gas bottle installation and removal

Over the course of running multiple combustion experiments empty gas supply bottles will need to be removed and full ones installed. This will be a simple operation requiring only that the fittings on the bottle be removed, the bottle clamp be disengaged, and the bottle removed. The new bottle can then be installed.

The following page illustrates the available Front Panel Operations for CIR.

Front Panel Operations



IOP/EPCU Changeout

The Input/Output Processor is a self contained package that uses a simple mounting system to attach to the rack. It is designed for easy removal for maintenance and replacement. The removal is accomplished by disconnecting all front interfaces, sliding out the package, disconnecting any rear mounted connections and removing the package from the rack.

The EPCU requires an ISS rack rotation in order to access the cooling water disconnects.

Diagnostic configuration

Since the FCF will be utilized by a large number of investigators, the diagnostics will need to be changed on a regular basis. This can be accomplished with a minimum of tools and crew time due to the use of a common mounting plate in the CIR that provides easy access to and easy removal of diagnostic packages.

Experiment Execution

While it is not currently possible to describe all experiment executions, it is reasonable to assume that they will all follow the same general flow.

After any new equipment is installed and consumables replenished, the FCF team request power enabled at the CIR. The FCF team then sends the command to the IOP to power up the Combustion Element. This includes the necessary diagnostics, IPSUs and the FOMA.

Once the FCF team is satisfied that the Combustion element is operating properly, the PI can send the command to power up the experiment specific equipment.

When the PI and the FCF team are satisfied that the facility is operating properly, experiments can be performed.

Conduct test matrix.

Experiment will run until current matrix is complete or is instructed to terminate for any reason. Operational data will be downlinked to observe experiment status. Science data will be downlinked to the extent possible during the experiment and will be stored until data can be downlinked. *If data from one test point is required to be analyzed prior to the next test point then the facility will be placed in downlink or low power mode while the data is downlinked and analyzed.*

After the last test in the current matrix, the facility can be shut down or reconfigured for a new experiment run.

The following page illustrates a Diagnostic Changeout / Reconfiguration for CIR.

Diagnostic Changeout/Reconfiguration